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MX SITING INVESTIGATION GEOTECHNICAL SITING STATUS REPORT. VOLU--ETC(U)

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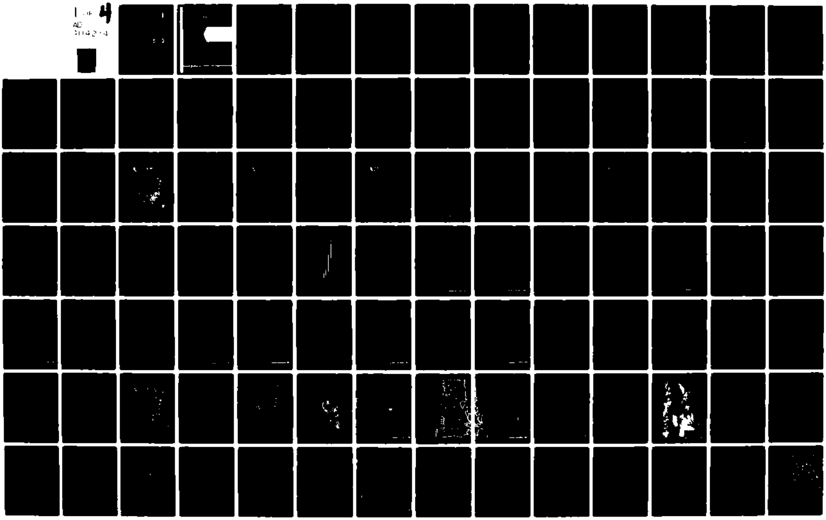

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VOLUME 1

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Volume I is text describing geotechnical data for Air Force MX project for areas of the Great Basin, Sonoran Desert, Highlands, Rio Grande, Southern High Plains, and Central High Plains. Coarse, intermediate, fine, and characterization screening projects indicate candidate sites for MX basing.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

MX SITING INVESTIGATION GEOTECHNICAL SITING STATUS REPORT

VOLUME 1

21 JUNE 1978

FUGRO NATIONAL INC

FOREWORD

This Geotechnical Siting Status Report presents the primary elements of Fugro National's program since approximately the beginning of Fiscal Year 1977. Two volumes make up the report; Volume I is the main body of text with support data, and Volume II contains oversized folded maps in pockets.

The report leads chronologically through the phases of the geotechnical siting program highlighting objectives, scopes and methods, results and discussing some of the more important findings. Sections 3.0 (CHARACTERIZATION STUDIES) and 5.0 (GEOTECHNICAL SUPPORT STUDIES) present summaries and specific examples of the extensive data bank utilized for Candidate Siting Region selection, ranking and support of MX systems analysis. Many activities which have data analysis currently in progress are addressed and results or conclusions are considered representative but preliminary. This is true of portions of Sections 3.3 through 3.6 and 4.0. Detailed data can be requested through SAMSO/MN, Norton Air Force Base, California.

A brief description of future geotechnical programs outlines both the broad near-term objectives and planned activities, and the plans for specific support programs. A milestone chart indicates near term schedule objectives which accompany suggested longer term program elements.

ACRONYMS

CDA - Candidate Deployment Area

CDP - Candidate Deployment Parcel

CDS - Candidate Deployment Site

CONUS - Conterminous United States

CSP - Candidate Siting Province

CSR - Candidate Siting Region

DA - Deployment Area

DP - Deployment Parcel

DS - Deployment Site

SP - Siting Province

SR - Siting Region

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EXECUTIVE SUMMARY

INTRODUCTION

The geotechnical project is bounded by three fundamental issues:

- the requirement to survey large land areas and identify geotechnically suitable regions for MX deployment;
- the requirement for geotechnical information to support fundamental system design and cost evaluations;
- the requirement to furnish the proper level of needed information to meet program schedules and milestones.

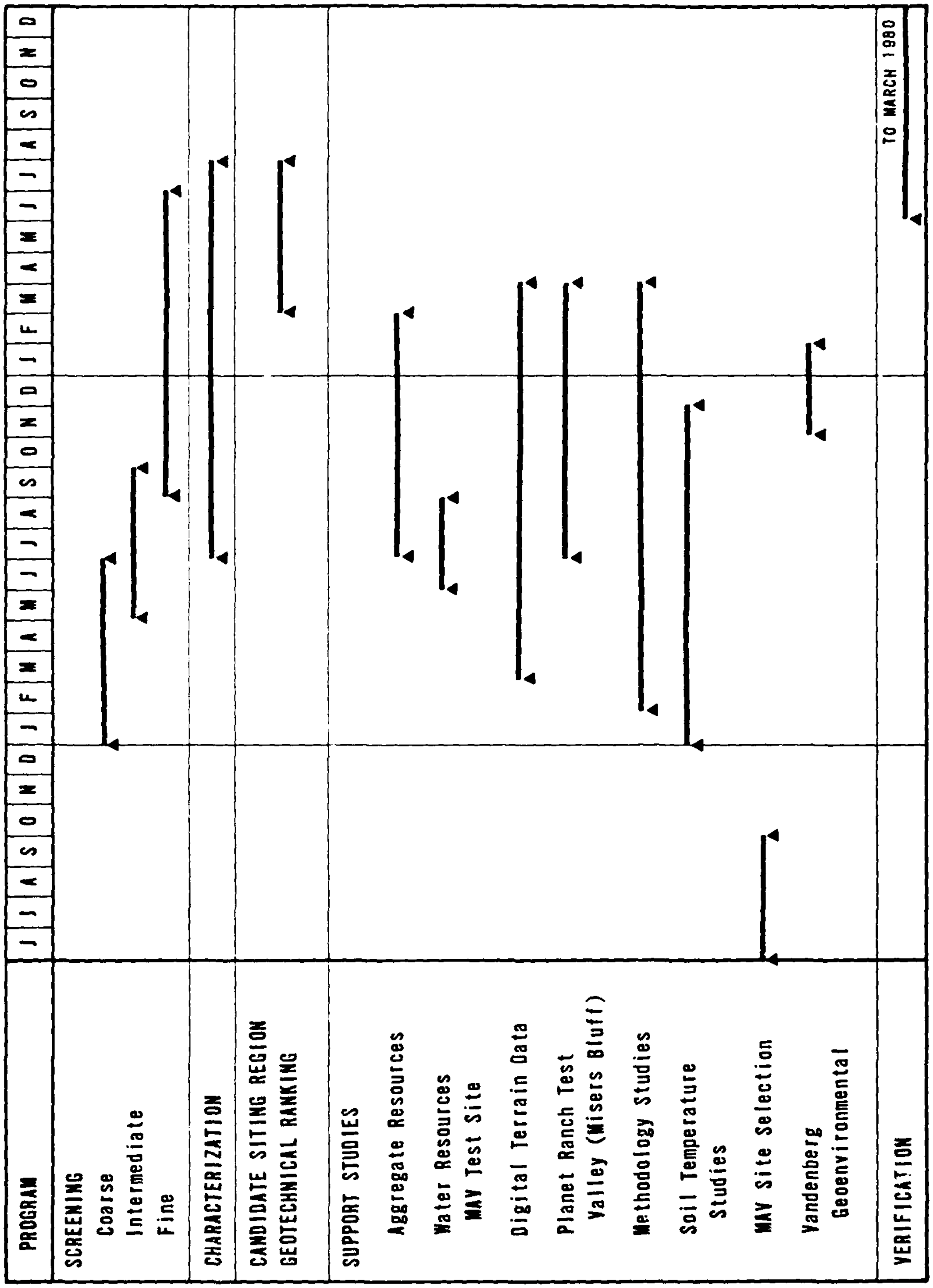
The technique being used to identify, rank and select the best geotechnically suitable region and specific areas is a multi-stage survey process. A similar process is used in surveying large areas for specific economic mineral resources. The whole area is tested for feasibility of mineral occurrence; those areas that are feasible are then rated for best potential. The best potential areas are surveyed in detail to select specific sites to be tested for mineral occurrence. A modification of the multistage technique was required for MX, in that survey criteria were developed for each step using three levels of screening: (1) Coarse, (2) Intermediate, and (3) Fine. Each step in establishing screening criteria was directly related to the level of development of the MX system or subsystem design.

As the geotechnical surveys progressed, it became apparent that some MX subsystems required information that was unavailable.

The requirement to fill these data gaps was integrated with the fundamental task of geotechnical surveying to identify suitable areas (Table ES-1).

The requirement for higher and complex levels of information as the MX program becomes more focused, is a fundamental determinant of geotechnical efforts. The project has maintained a level and schedule of information gathering and reporting that is consistent with the stated needs of other MX program elements.

The integrated approach of screening levels to meet MX system requirements and the development of MX system specifications to establish goetechnical screening criteria demonstrates the interactive nature of the project.



MX GEOTECHNICAL SITING PROGRAM

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE
ES-1

FUGRO NATIONAL, INC.

SCREENING STUDIES

To facilitate an orderly and defensible process of geotechnical Candidate Siting Region identification, a three-staged screening approach was used consisting of: (1) Coarse Screening of the entire conterminous United States; (2) Intermediate level screening of remaining large, apparently suitable siting regions; and (3) Fine Screening of specific siting areas with progressively higher probabilities of geotechnical suitability.

Coarse Screening

Criteria for the Coarse Screening were essentially exclusionary, eliminating regions from further contention on the basis of proximity to large cities and areas of cultural or environmental significance. Land surface slopes greater than a ten percent grade (~six degrees) and areas with shallow hard rock or water table (less than 50 feet deep; 15 m) were also excluded. Remaining whole parcels or close aggregate parcels less than 500 square nautical miles (1700 km^2) in size were considered unsuitable for practical siting.

Approximately 65 percent of the conterminous U. S. did not meet the coarse criteria of suitability. Thirty percent (225,000 nm^2; 772,000 km^2) of the remaining 780,000 square nautical miles (2,675,000 km^2) appeared highly suitable, whereas the remainder was potentially unsuitable with conditions inadequately defined by Coarse Screening data. The entire 780,000 square nautical miles (2,675,000 km^2) were evaluated in Intermediate Screening.

The greatest percentage of the highly suitable 225,000 square nautical miles (772,000 km^2) occurred in the Basin and Range, Great Plains and Central Lowlands physiographic provinces in the western and central United States.

Intermediate Screening

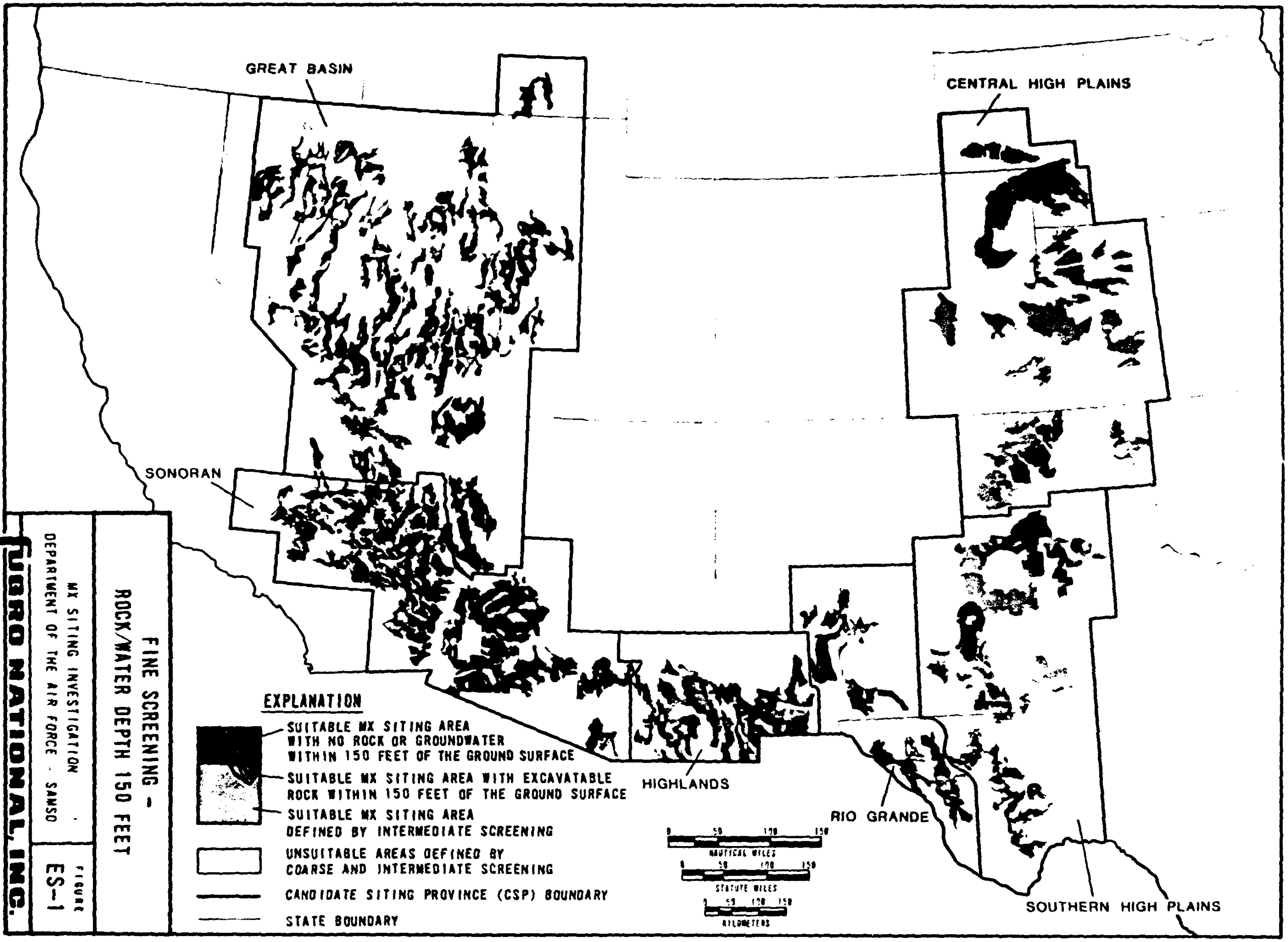
Intermediate Screening, a joint program with Defense Mapping Agency, began as a more detailed assessment of the depth to rock and water, and surface slope criteria, plus an evaluation of areas of adverse low, rolling terrain. Additional criteria, designating high potential resource and mining areas as unsuitable, were added.

Approximately 110,000 square nautical miles (377,000 km^2) of suitable area remained following this Intermediate level screening. Eighty-five percent of this was located in suitable soil, and the rest in suitable excavatable rock. Poorly distributed area and excavatable rock were considered less desirable for MX deployment, leaving approximately 83,000 nm^2 (285,000 km^2) for study in Fine Screening.

Fine Screening

Fine Screening areas had a roughly U-shaped configuration from the Nevada Basin and Range across the southwestern border states to North Dakota. The initial phase did not result in major exclusions but rather refined the suitable area boundaries and demonstrated the effects of the more comprehensive cultural considerations which produced restricted use zones covering one-third of the area.

An evaluation of depth to rock and water at 150 feet (46 m) rather than 50 feet (15 m), as in the previous screening efforts, was brought about by increased attention to the vertical shelter concept. The recently completed evaluation of the Intermediate Screening suitable area revealed a potential loss of area from 83,000 square nautical miles (285,000 km^2) to approximately 56,000 square nautical miles (192,000 km^2). Primary effects were due to water in the Great Plains physiographic province (Figure ES-1).



FINE SCREENING - ROCK/WATER DEPTH 150 FEET

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE ES-1

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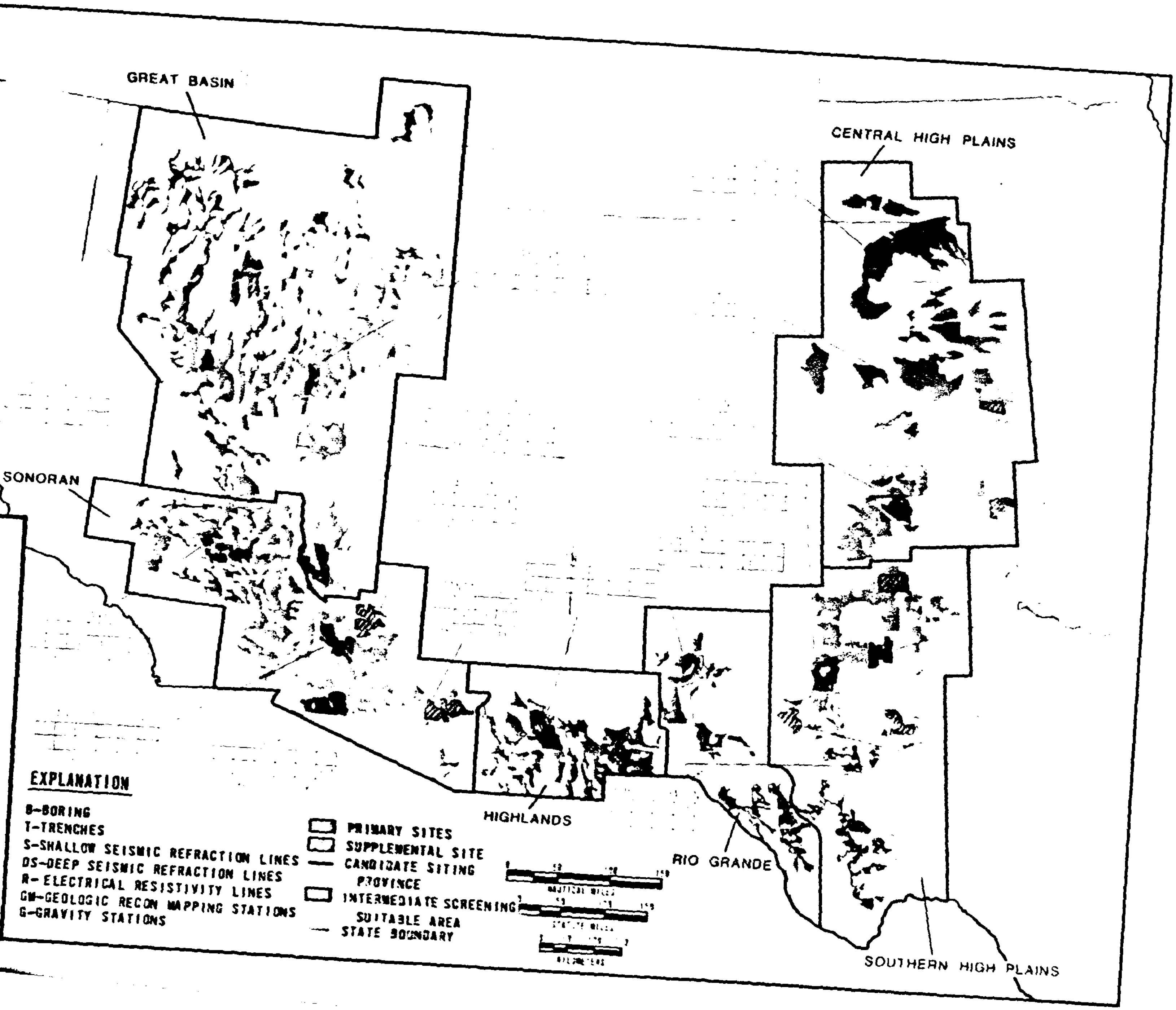
CHARACTERIZATION

Screening studies indicated that insufficient published data are available to adequately evaluate and rank the relative favorability of these large suitable land areas. Characterization was a refinement of the screening process whereby the necessary geotechnical information was developed to support the broader MX system design activities that were taking place concurrently and to provide a firmer basis from which to geotechnically rank the remaining suitable area considering different alternative basing modes.

Characterization involved field studies to obtain data for site selection and ranking; twenty-five individual prime and supplemental characterization sites were selected. Following the Characterization studies, geotechnically similar areas within each CSP were delineated and the key ranking factor parameters were defined quantitatively (e.g. engineering, goephysical properties, percentage geologic units) and cataloged. Figure ES-2 shows these areas and the field activities performed in each; a detailed inventory of data gathered is presented in Section 3.0.



CHARACTERIZATION PROGRAM

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE ES-2

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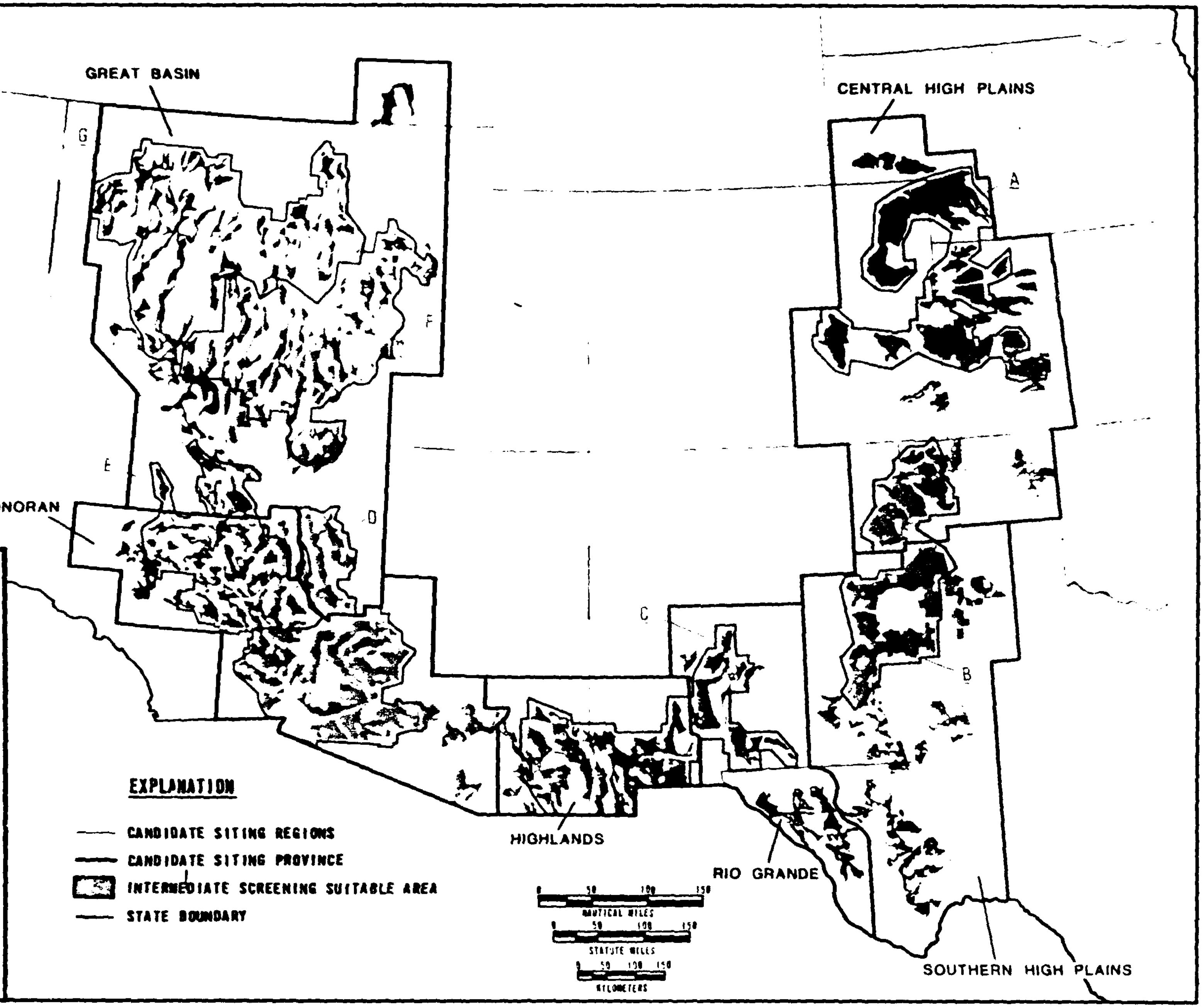
CANDIDATE SITING REGIONS GEOTECHNICAL RANKING

Resulting Fine Screening suitable area distributions, primarily based on degree of compactness and contiguity were overlain by the boundaries of geotechnically similar areas delineated during characterization. Mutually agreeable aggregations of suitable area based on these results were selected as Candidate Siting Regions (CSRs) and designated by the letters A through G clockwise from northeastern Colorado (Figure ES-3).

These seven CSRs were ranked relative to one another for the hard vertical shelter and in-line hybrid trench basing modes using a cost measures decision methodology. All key geotechnical variables were evaluated for their effect on construction costs for each basing mode in each CSR (Figure ES-4). These cost effects were summed for each CSR using nominal cost figures; the lowest sum was normalized to 100 percent cost per linear foot of trench or per shelter, and direct and intuitively comprehensible comparisons were made (Figure ES-5). These graphs show that the vertical shelter is strongly influenced by the low surface soil bearing strengths for roads in CSR A; otherwise there is not a great variation for this nominal cost case indicating the effectiveness of the screening criteria and their application.

These ranking evaluations should be considered representative, but preliminary. Probabilistic assessments of the expected variation from nominal costs for each variable for each CSR, and for three basing modes (including horizontal shelter--loading dock), is in progress.



CANDIDATE SITING REGIONS

MX SITING INVESTIGATION
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FIGURE ES-3

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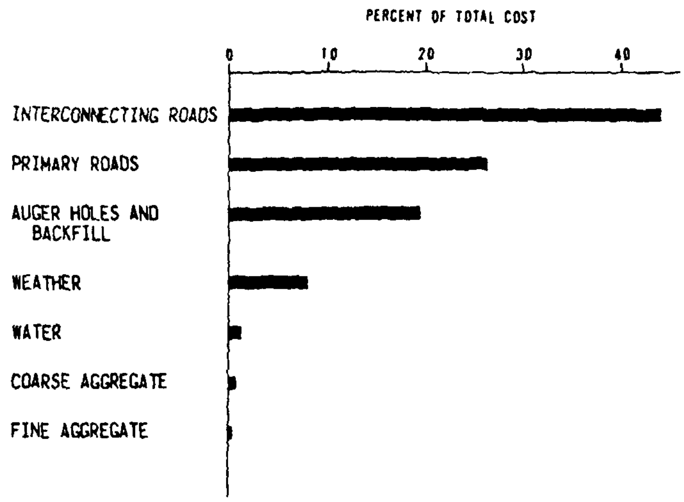
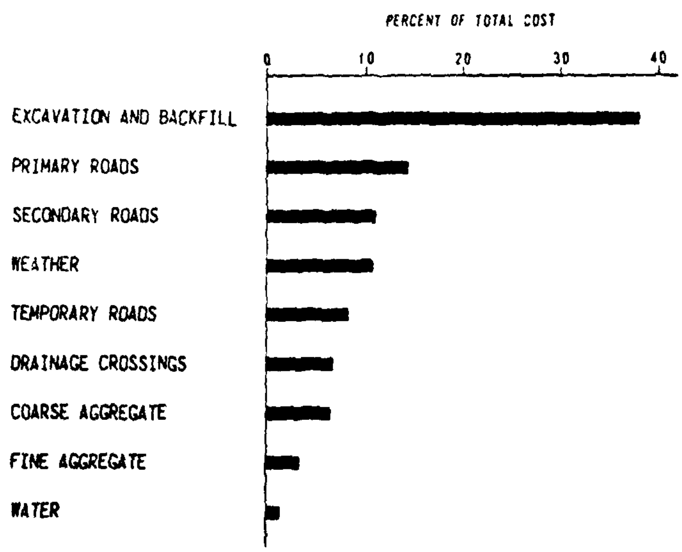


HARD VERTICAL SHELTER



IN-LINE HYBRID TRENCH

RELATIVE IMPORTANCE OF GEOTECHNICAL FACTORS
HARD VERTICAL SHELTER AND HYBRID TRENCH

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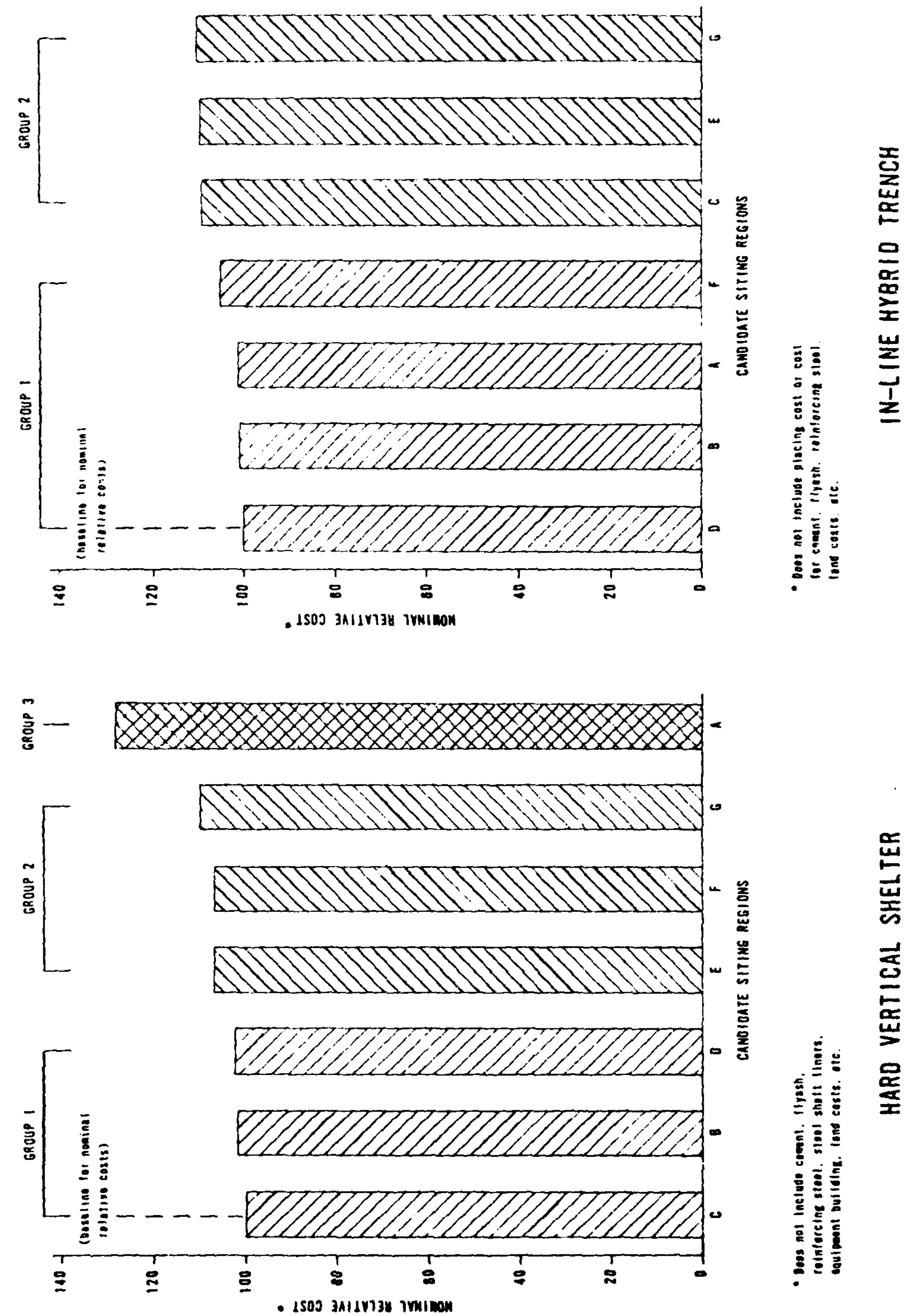
FIGURE ES-4

FUGRO NATIONAL, INC.



PRELIMINARY CSR GEOTECHNICAL RANKING
HARD VERTICAL SHELTER
AND IN-LINE HYBRID TRENCH

MX SITING INVESTIGATION
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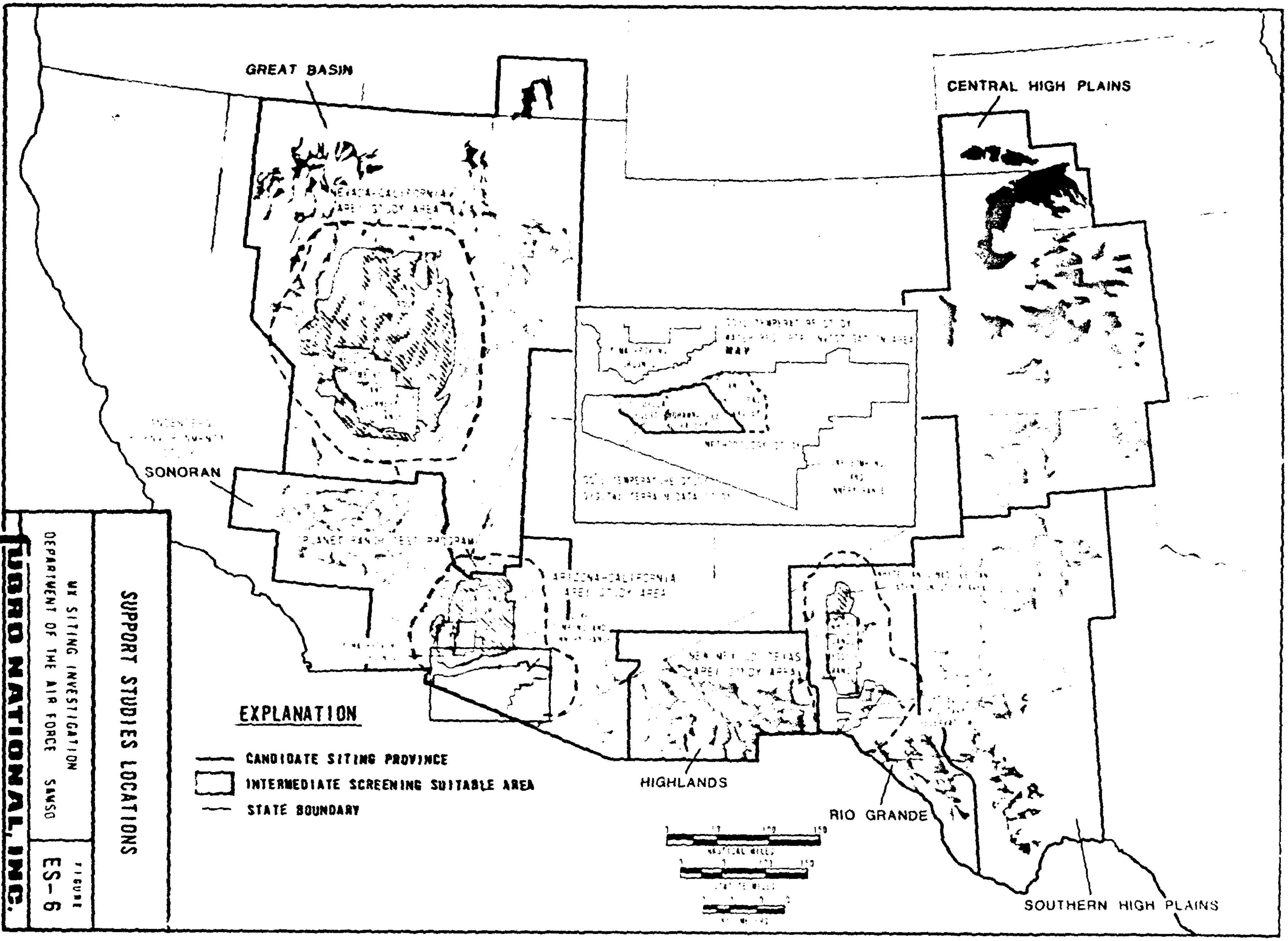
FIGURE ES-5

FUGRO NATIONAL, INC.

GEOTECHNICAL SUPPORT STUDIES

Geotechnical support studies are designed to provide data for development and design of specific MX subsystems; to date these studies have been on the following topics: 1) resources (concrete aggregate, water, energy, other raw materials); 2) digital terrain data/mapping; 3) survivability and hardness testing; 4) geotechnical methodology investigation; 5) geo-environmental; 6) shallow soil temperature monitoring; and 7) prototype test area selection. Geographic distribution of studies is shown in Figure ES-6.



SUPPORT STUDIES LOCATIONS

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE ES-6

FUGRO NATIONAL, INC.

FUTURE GEOTECHNICAL PROGRAMS

Geotechnical Verification studies are needed to 1) confirm characterization data extrapolations, 2) verify a prime CSR for Deployment Area Selection, and 3) ensure viability of two alternative CSRs. Field, laboratory and office studies will be required to provide sufficient data to accomplish these objectives; various program mixes are possible considering relative CSR rankings and system milestones.

Geotechnical support studies are essential to provide data for MX subsystem design (Table ES-2) and criteria development. Geotechnical Verification requires the following studies: 1) road design; 2) excavation and slope stability; 3) aggregate suitability; 4) water resources; 5) earthquake engineering; 6) backfill/soil structure interaction; 7) geoenvironmental; 8) security and C^3; and 9) survivability and hardness.

Highlights of schedules for the future geotechnical programs are outlined on Table ES-3. These schedules will allow timely interaction with other MX systems programs leading to Milestone II and Deployment Area Selection.

Preconstruction surveys include photogrammetric surveys and site-specific geotechnical investigation. The photogrammetric studies are needed to prepare large scale topographic maps and digital terrain data needed for preliminary design. Geotechnical investigations need to be performed at structure

FACILITIES DESIGN
- o Soils Engineering Parameters
- o Geologic Hazards
- o Seismicity
- o Shallow Soil Temperatures
- o Soil Conductivity

CONSTRUCTION FEASIBILITY COST AND SCHEDULE ESTIMATES
- o Excavatability
- o Slope Stability
- o Backfill Suitability
- o Surface CBRs
- o Location Raw Construction Materials
- o Terrain Variations
- o Field Investigation Techniques and Costs

CONSTRUCTION EQUIPMENT DESIGNS
- o Excavatability Variations
- o Stable Slope Angles
- o Topographic Grade
- o Local Relief

CONSTRUCTION MATERIALS
- o Coarse and Fine Concrete Aggregate
- o Water for Construction and Comsumption
- o Base Course

CONSTRUCTION COORDINATION AND CONTROL
- o Backfill Characteristics
- o Location Borrow Sources
- o Quality of Aggregates and Water

VULNERABILITY AND HARDNESS
- o Depth to Rock and Water
- o Variations in Seismic Velocities
- o Particle Size Gradations
- o Density and Moisture Content

ENVIRONMENTAL IMPACTS
- o Soil Particle Size and Dust Potential
- o Ground Water Quality and Quantity
- o Geologic Hazards
- o Economic Mineral Resources
- o Surface Water and Drainages

COMMUNICATIONS, COMMAND AND CONTROL AND GUIDANCE
- o Macro and Micro Relief
- o Gross Topography, Area Shape and Size
- o Soil Dielectric Constant
- o Regional and Local Gravitational Fields

SECURITY AND SAFETY
- o Terrain
- o Surface Soil Strengths
- o Gross Topography, Area Shape and Size
- o Seismic or Ambient Ground Noise

VEHICLE POWER REQUIREMENTS
- o Topographic Grade and Variations
- o Macro and Micro Relief
- o Surface CBRs

OPERATIONAL MAINTENANCE AND PERFORMANCE STANDARDS
- o Surface Flooding Potential
- o Soil Particle Size (Dust)
- o Soil Strengths and Settlement Potential
- o Liquefaction Potential
- o Seismicity
- o Geologic Hazards

MX SITING INVESTIGATION
GEOTECHNICAL DATA
SUPPORTING MAJOR SYSTEMS ELEMENTS

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE ES-2

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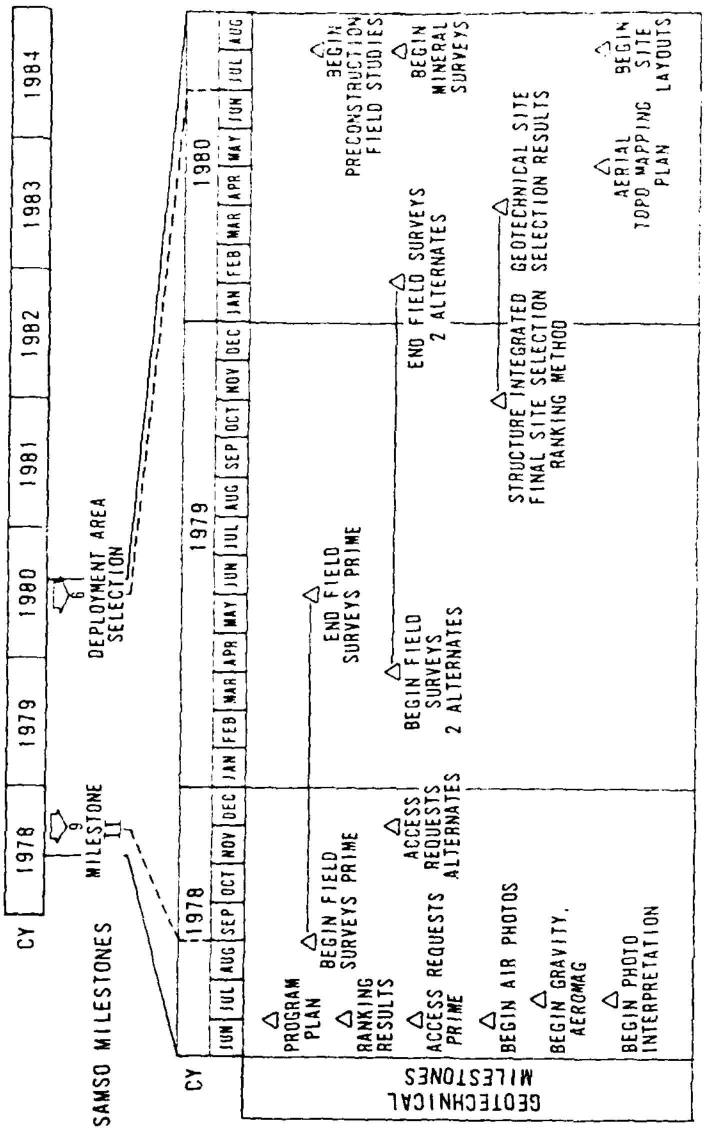

PROPOSED MX GEOTECHNICAL ACTIVITIES

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

TABLE
ES-3

FUGRO NATIONAL, INC.

locations after preliminary field layouts have been completed. These studies will provide more detailed information than was possible during the Verification program.

1.0 INTRODUCTION

The primary task of the MX geotechnical program is to provide necessary technical information and consultative support for the identification and selection of lands in the United States that are most suitable for deploying a full MX ICBM system. Therefore, the objective of the geotechnical program is to establish and quantify geotechnical advantages and constraints that govern land suitability based on MX system requirements, basing modes and deployment concepts, and to use these advantages and constraints to identify and rank suitable deployment areas.

A cost effective, milestone oriented, and multiphased effort has been underway to implement programs and achieve project objectives. The detail and confidence level of technical information provided increases, step-by-step, to meet the demands of progressively more definitive MX systems requirements and land selection decisions. This system provides for progressive geotechnical screening and evaluation of land in three stages; 1) Coarse, 2) Intermediate, and 3) Fine. In addition to the developed screening criteria, data for other engineering, construction and deployment concept specifications have been gathered in the field and are being used to rank identified suitable regions relative to each other. This is being accomplished for three basing modes (hard vertical shelter; in-line hybrid trench; and loading dock horizontal shelter) and two deployment concepts (compact regions; and dispersed aimpoints).

Additional important program tasks provide geotechnical data and information to support the development and design of subsystems, including:

- o Facilities Design
- o Construction Equipment Design and Selection
- o Construction Technique Selection
- o Transportation Vehicles and Road Design
- o Security System Design
- o Communications, Command and Control
- o Survivability and Hardness Determinations
- o Detectability Calculations
- o Environment Assessment and Siting

The dual role of the geotechnical project, i.e. guiding the land selection and providing key support data, led to parallel supportive efforts. Overall evolution of specific system and basing mode concepts established discipline oriented exclusionary factors, while broad subsystem requirements provided additional geotechnical bounding conditions. This led to development of the set of Coarse Screening criteria that were applied in a binary fashion and eliminated large land areas from further consideration.

More complete systems descriptions and basing mode definitions supported further refinement of subsystem specifications. These further constrained the geotechnical acceptability factors and Intermediate Screening criteria were developed and binarally applied.

The process of developing Fine Screening criteria was accomplished by direct interrogation of MX system and subsystem design engineers and scientists. Bounding engineering values, generally associated with systems and cost effectiveness, were established. The resulting Fine Screening criteria were, and are, being used to modify the remaining suitable parcels and aggregate the parcels into areas, and the areas into select regions capable of accepting full-scale deployment of a nominal force (200 missiles).

In the land screening process, it became apparent that the suite of geotechnical conditions, acceptable to MX, could be associated with fundamental physiographic and tectonic provinces. However, it also became apparent that existing geotechnical data from the near surface (MX construction zone) was lacking. To cost effectively gather the needed data, model characterization areas typical of overall CSP conditions were selected. Both field and laboratory studies have been completed in these Characterization areas. The acquired information is being used to geotechnically rank candidate siting regions (CSRs) and establish the most cost effective techniques for performing geotechnical verification surveys. The analyzed data are also being provided, as required, to subsystem and discipline oriented engineers, to more firmly establish design specifications.

2.0 SCREENING STUDIES

Geotechnical screening studies, initiated in January 1977, will be complete when a region or regions are selected for geotechnical Verification studies (Figure 2.0-1). The initial screening schemes, Coarse and Intermediate, were designed to identify areas in the conterminous United States that are technically acceptable for deployment of an MX system. An important corollary was to provide full documentation of the approach and results. Whereas Coarse and Intermediate studies were concerned with identifying suitable areas by applying exclusion criteria, Fine Screening studies were designed to more closely define cultural and geotechnical conditions within areas already found to be technically suitable. This required development of criteria more sensitive to basing modes and cultural features.

GEOTECHNICAL SCREENING AND VERIFICATION MILESTONES

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 2.0-1

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2.1 COARSE SCREENING

2.1.1 Objectives and Criteria

Coarse Screening studies were designed to provide a method for rapid and cost-effective elimination of large portions of the conterminous United States unsuitable for MX deployment. The specific objectives were to:

1. Identify large portions of the United States where deployment of an MX system would be completely unreasonable or technically so difficult as to warrant no further consideration.

2. Define suitable MX siting regions that required more detailed investigation.

3. Establish regions for non-geotechnical investigations to proceed in parallel with geotechnical studies.

The Coarse Screening criteria (Table 2.1-1) were applied on a regional scale to achieve the objectives at minimum cost.

2.1.2 Process

Coarse Screening involved the collection and analysis of regional geotechnical data at various scales and levels of detail. The potential suitability of all lands within the conterminous United States was evaluated and areas which clearly did not satisfy basic criteria were excluded. Data were analyzed by physiographic units (Figure 2.1-1) that have similar topographic, geomorphic, hydrologic and geologic conditions.

CRITERIA[1]	DEFINITION AND COMMENTS[2]
SURFACE ROCK AND ROCK OCCURRING WITHIN A NOMINAL 50 FEET OF THE GROUND SURFACE	Rock is defined as any earth material which is not rippable by conventional excavation methods. Where available, seismic P-wave velocities were evaluated in the determination of rock conditions. In general materials with velocities greater than 7000 fps were considered as rock.
SURFACE WATER AND GROUND WATER OCCURRING WITHIN A NOMINAL 50 FEET OF THE SURFACE	Surface water includes all significant lakes, reservoirs, swamps, and major perennial drainages. Water which would be encountered in a nominal 50-foot excavation was considered in the application of this criterion. Depths to ground water resulting from deeper confined aquifers were not considered.
CULTURAL	All significant federal and state forests, parks, monuments, and recreation areas. All significant federal and state wildlife refuges, ranges, preserves and management areas, and indian reservations.
QUANTITY/DISTANCE	Eighteen nautical mile exclusion arcs from cities having populations (1970) of 25,000 or more. Three nautical mile exclusion arcs from cities having populations (1970) of between 5,000 and 25,000.
TOPOGRAPHIC	All areas having surface gradients exceeding 10 percent as determined from maps at scale 1:500,000.
MINIMUM PARCEL (SECONDARY CRITERIA)	All parcels or aggregate parcels having total area less than 500 nm^2. Individual parcels must be less than 10 nm from adjacent suitable parcels to be included in the aggregate total.

NOTES: (1) Data used in applying the siting criteria were compiled on separate overlays and composited to form the final exclusion map.
(2) Additional data concerning application and limitations of each exclusion criterion are included in Appendix B.

COARSE SCREENING CRITERIA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE 2.1-1

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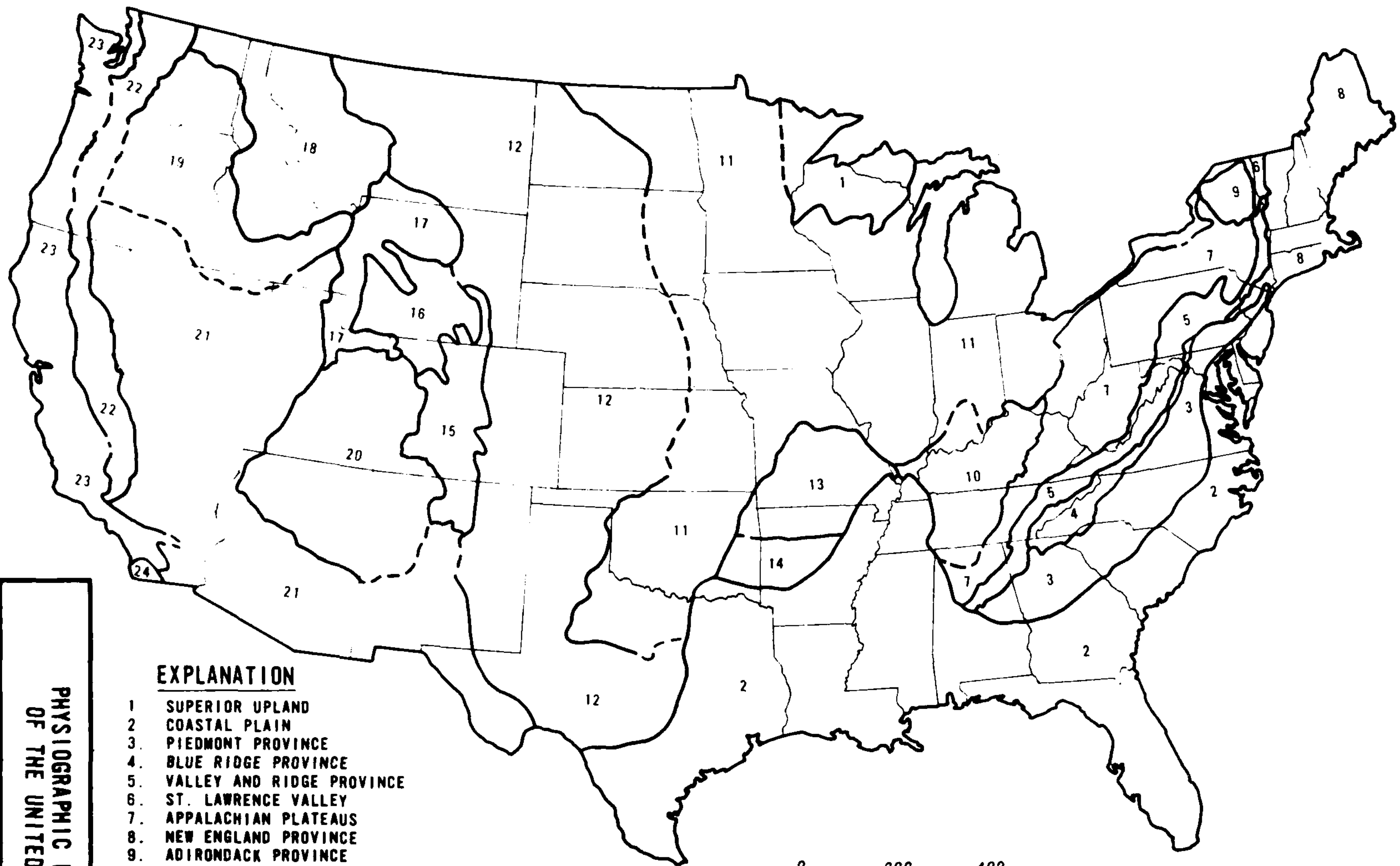

EXPLANATION

1 SUPERIOR UPLAND
2 COASTAL PLAIN
3. PIEDMONT PROVINCE
4. BLUE RIDGE PROVINCE
5. VALLEY AND RIDGE PROVINCE
6. ST. LAWRENCE VALLEY
7. APPALACHIAN PLATEAUS
8. NEW ENGLAND PROVINCE
9. ADIRONDACK PROVINCE
10. INTERIOR LOW PLATEAUS
11. CENTRAL LOWLAND
12. GREAT PLAINS PROVINCE
13. OZARK PLATEAUS
14. OUACHITA PROVINCE
15. SOUTHERN ROCKY MOUNTAINS
16. WYOMING BASIN
17. MIDDLE ROCKY MOUNTAINS
18. NORTHERN ROCKY MOUNTAINS
19. COLUMBIA PLATEAUS
20. COLORADO PLATEAUS
21. BASIN AND RANGE PROVINCE
22. CASCADE-SIERRA MOUNTAINS
23. PACIFIC BORDER PROVINCE
24. LOWER CALIFORNIAN PROVINCE

Modified after Fenneman, 1946, Physical Divisions of the United States; U S Geol. Survey Map

0 200 400
STATUTE MILES

0 200 400
NAUTICAL MILES

0 200 400
KILOMETERS

—— BOUNDARY OF PHYSIOGRAPHIC PROVINCE

— — INDICATES GENERALIZED PHYSIOGRAPHIC PROVINCE BOUNDARIES WHERE POORLY DEFINED

PHYSIOGRAPHIC PROVINCES
OF THE UNITED STATES

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE 2.1-1

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2.1.3 Results

Coarse Screening resulted in the elimination of approximately 65 percent of the conterminous United States from further consideration for MX Siting. The remaining area totaled 782,570 nm^2 (2,684,200 km^2). These lands were segregated into four categories:

1. Established suitable lands (226,630 nm^2; 777,340 km^2);
2. Potentially suitable lands with inadequately defined rock conditions (268,430 nm^2; 920,700 km^2);
3. Potentially suitable lands with inadequately defined ground-water conditions (228,380 nm^2; 783,340 km^2); and
4. Potentially suitable lands having both rock and ground-water conditions which are inadequately defined (59,130 nm^2; 202,820 km^2).

Table 2.1-2 summarizes areal distribution of suitable and potentially suitable areas that were identified.

Important results from Coarse Screening include:

- o Approximately 35 percent (782,570 nm^2; 2,684,200 km^2) of the United States was classed as suitable or potentially suitable land.
- o Critical application of criteria indicated that 226,630 nm^2 (777,340 km^2) was "best" suited for MX siting and warranted further study.
- o The eastern portion of the United States contains only a small amount of clearly suitable area.

INTERMEDIATE SCREENING STUDY GROUP	SUITABLE AREA (nm^2)	POTENTIALLY SUITABLE AREA (nm^2)			PRIMARY EXCLUSION FACTORS [a]	PRINCIPAL PHYSIOGRAPHIC PROVINCE (INCLUSIVE)
		ROCK CONDITIONS INADEQUATELY DEFINED	GROUND-WATER CONDITIONS INADEQUATELY DEFINED	ROCK AND GROUND-WATER CONDITIONS INADEQUATELY DEFINED		
NEVADA	16.315	0	0	0	Depth to rock Topography	Basin and Range
ARIZONA	13.572	3.561	0	4	Cultural Depth to rock	Basin and Range
CALIFORNIA	13.676	1.339	1.368	0	Topography Depth to rock	Basin and Range
NEW MEXICO	9.525	7.347	7.007	3.194	Depth to rock Cultural	Basin and Range Great Plains
UTAH	1.815	3.457	0	123	Topography Depth to rock	Basin and Range
OKLAHOMA	4.171	19.114	3	0	Quantity Distance Depth to water	Great Plains Central Lowland
TEXAS	30.433	65.947	17.251	0	Depth to rock Quantity/Distance	Great Plains Coastal Plain
NORTH DAKOTA	28.124	8.192	1.162	265	Depth to rock Depth to water	Great Plains Central Lowland
SOUTH DAKOTA	18.263	10.777	181	0	Depth to rock Cultural	Great Plains Central Lowland
NEBRASKA	30.904	11.273	19	0	Depth to rock	Great Plains
COLORADO	11.486	10.890	776	0	Topography Depth to rock	Great Plains
MONTANA	20.508	29.337	10	0	Depth to rock Cultural Topography	Great Plains

MONTANA	20.508	29.337	10	0	**Depth to rock** Cultural Topography	**Great Plains**
MID-CONTINENT	5 765	7.856	8 342	2.459	Depth to rock Depth to water	Great Plains Central Lowland
WYOMING	8.981	29.280	0	19	Cultural Topography	Wyoming Basin Great Plains
KANSAS	284	24.460	14.901	2.299	Quantity Distance Depth to water	Great Plains Central Lowland
SOUTHEASTERN	9.223	0	55.842	9.457	Depth to water Quantity Distance	Coastal Plain
GREAT LAKES	0	11	35.922	27.845	Quantity Distance	Central Lowland
PACIFIC NORTHWEST	3.514	0	8,970	385	Depth to rock Topography	Basin and Range Columbia Plateau
MID-ATLANTIC	0	13.885	23.602	2.416	Quantity Distance Depth to rock	Piedmont Coastal Plain
MINNESOTA	0	0	27.745	4.036	Depth to rock Cultural	Central Lowland
IOWA	0	0	20.275	3.511	Quantity Distance	Central Lowland
NORTHEASTERN	71	16.141	0	2.787	Topography Quantity Distance	New England
APPALACHIAN PLATEAU	0	5.562	5.005	327	Depth to rock Topography	Interior Low Plateau
TOTAL	226,630	268,429	228,381	59.127		

(a) Primary exclusion factors are those criteria which were primary in the exclusion of land within each intermediate screening study group. These appear in order of importance within each study group, with the exception of the Montana and Kansas Groups in which they were of nearly equal importance.

AREAL DISTRIBUTION OF SUITABLE AND POTENTIALLY SUITABLE AREAS

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

TABLE 2.1-2

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- o Cultural exclusion criterion had the greatest affect on land reduction. Approximately 1,060,000 nm^2 (3,635,800 km^2) was excluded in the Great Lakes region, coastal Florida, and southern California.
- o Scarcity of near surface data related to rock and water depths resulted in retention of large potentially suitable areas.
- o The screening criterion which had the least overall effect on area reduction was depth to water.
- o Exclusion of mountainous regions on the basis of topography and exposed rock conditions resulted in rejection of large quantities of land in the western U.S.
- o Shallow ground water was the principal cause for exclusion of lands of the Pacific Northwest and the Mississippi Embayment.
- o Surface rock conditions and/or depth to rock are poorly defined in the Great Plains, Central Lowland, and New England physiographic provinces.
- o Ground-water conditions are poorly defined in the northeast portion of the Central Lowland and Coastal Plain physiographic provinces.
- o Rock and ground-water conditions are poorly described in the glaciated northeast portion of the Central Lowland physiographic province.

2.2 INTERMEDIATE SCREENING STUDY

2.2.1 Objectives and Criteria

The Intermediate Screening study was initiated to apply more critical and detailed criteria to suitable lands remaining following Coarse Screening.

The objectives were to:

1. Rapidly assess the lands classed as suitable and potentially suitable following Coarse Screening by applying new siting criteria and more detailed application of existing geotechnical criteria;
2. Provide sufficient technical documentation of the screening process to fully justify site selection decisions;
3. Provide screening results for nongeotechnical investigations, such as facilities design and hardness modeling studies;
4. Group the remaining suitable lands into Candidate Siting Provinces (CSPs) that possess similar geotechnical characteristics.

Criteria such as quantity-distance, and depth to rock and water remained unchanged from Coarse Screening, except for increased detail of application (Table 2.2-1). Cultural, topographic and minimum parcel criteria changed appreciably, especially in terms of application. To expedite the Intermediate Screening process, a "single exclusion" approach was used. A positive response to a primary exclusion was adequate to class an area as unsuitable.

CRITERIA		DEFINITION AND COMMENTS
SURFACE ROCK AND ROCK OCCURRING WITHIN A NOMINAL 50 FEET OF THE GROUND SURFACE		Rock is defined as any earth material which is not rippable by conventional excavation methods. Where available, seismic P-wave velocities were evaluated in the determination of rock conditions. In general, materials with velocities greater than 7000 fps were considered as rock.
SURFACE WATER AND GROUND WATER OCCURRING WITHIN A NOMINAL 50 FEET OF THE GROUND SURFACE		Surface water includes all significant lakes, reservoirs, swamps, and major perennial drainages. Water which would be encountered in a nominal 50-foot excavation was considered in the application of this criterion. Depths to ground water resulting from deeper confined aquifers were not considered.
TOPOGRAPHIC	Percent Grade:	**Areas having surface gradients exceeding 10 percent as determined from maps at scale 1:250,000.**
	Relative Relief:	**Areas of characteristic terrain defined by a preponderance of slopes exceeding 5 percent as determined from maps at scales of 1:250,000, 1:62,500, and 1:24,000.**
		Areas having drainage densities averaging at least two ten-foot deep drainages per 1000 feet (measured parallel to contours, as determined from maps at scales of 1:24,000).
CULTURAL	Quantity/Distance:	Eighteen nautical mile exclusion arcs from cities having populations (1970) of 25,000 or more.
		Three nautical mile exclusion arcs from cities having populations (1970) of between 5,000 and 25,000.
	Land Use:	All significant federal and state forests, parks, monuments, and recreation areas.
		All significant federal and state wildlife refuges, grass lands, ranges, preserves and management areas.
		Indian reservations.
	Economic:	**High potential economic resource areas including oil and gas fields, strippable coal, oil shale and uranium deposits, and known geothermal resource areas (kgra's).**
		Industrial complexes such as active mining areas, tank farms and pipeline complexes.
	Minimum Parcel:	**All parcels or aggregate parcels having total area less than 500 nm^2. Aggregate parcels must be a minimum of 150 nm^2 to be included in the aggregate total and must not be isolated from adjacent suitable parcels by distances greater than 10 nm or by grades greater than 10 percent. Individual parcels may be further reduced in area if the combined or individual alignment of county, state and federal paved highways, railroads, aqueducts, or perennial streams is sufficiently dense to restrict the emplacement of a straight 10 nm trench.**

Shaded criteria are new or modified from Coarse Screening Study

INTERMEDIATE SCREENING CRITERIA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

TABLE 2.2-1

FUGRO NATIONAL, INC.

Once a parcel was rejected by any criterion it was not re-evaluated on the basis of other criteria.

2.2.2 Process

Intermediate Screening consisted of a detailed literature search and personal communication (both written and oral) with geologists, hydrologists and other professionals in state and federal offices. The literature search used computer indexed files from several sources:

1. State and Federal geological organizations (e.g., United States Geological Survey, Nevada Bureau of Mines and Geology);
2. Major non-governmental geological organizations (e.g., Geological Society of America, American Association of Petroleum Geologists); and
3. Computer searches in selected areas using Library of Congress, Geo-Ref., NTIS, NASA and Dissertation Abstracts.

No field or laboratory data were acquired in support of Intermediate Screening. Data pertinent to one or more MX screening criteria were compiled on 1:250,000 scale base maps.

The United States was divided into twenty-three study areas used as basic units for data collection, analysis, and compilation. Fugro National investigated areas in the western United States and the Defense Mapping Agency (DMAAC) investigated all areas east of the Mississippi River and those states on the west side of, and bordering, the Mississippi River.

2.2.3 Results

Drawings 2.2-A and 2.2-B present the results of Intermediate Screening. The 112,130 nm^2 (384,600 km^2) found suitable is restricted to the western United States; no eastern areas were identified as suitable by DMAAC.

Lands remaining after Intermediate Screening were divided into twelve (12) Candidate Siting Provinces (CSPs). These provinces (Drawing 2.2-A) form a broad U-shaped configuration over the west-central portion of the United States, coincident with the Basin and Range, Great Plains, Colorado Plateau and Northern Rockies physiographic provinces. Each CSP was grouped in accordance with similar geotechnical characteristics.

Suitable siting area was delineated as soil and excavatable rock. Suitable excavatable rock was assigned to sedimentary formations which could be excavated to a depth of 50 feet with conventional equipment. Table 2.2-2 indicates the distribution and ownership of suitable lands in all the CSPs. Approximately 94,110 nm^2 (322,800 km^2; 85 percent) of the suitable area is soil. The remaining 18,020 nm^2 (61,810 km^2; 15 percent) is excavatable rock.

Based on the investigation results, approximately 83,480 nm^2 (286,340 km^2) (Table 2.2-3) of suitable area was selected for Fine Screening. The appropriate CSPs for Fine Screening/Characterization field studies were selected as follows: Great Basin, Sonoran, Highlands, Rio Grande, Southern High Plains, and Central High Plains.

STATE	TOTAL SUITABLE NM^2	INCLUSIVE CSP(S)	SUITABLE AREA		LAND OWNERSHIP CONDITIONS		
			NONROCK	ROCK	DoD AREA	BLM AREA	* OTHER (NM^2)
ARIZONA	15670	Highlands	3680		0	780	2900
		Great Basin	1990		0	940	1050
		Plateau	510	850	0	0	1360
		Sonoran	8660		2080	3340	3240
CALIFORNIA	9160	Sonoran	8450		1340	5120	1990
		Great Basin	710		0	640	70
COLORADO	6180	Central High Plains	4920	1260	0	0	6180
IDAHO	1340	Northern Rockies	820		0	520	300
		Great Basin	520		0	170	350
KANSAS	4980	Central High Plains	4470	510	0	0	4980
MONTANA	9670	Montana		9670	0	1440	8230
NEBRASKA	3180	Central High Plains	3180		0	0	3180
NEVADA	19450	Great Basin	19090		1360	15990	1740
		Sonoran	360		0	350	10
NEW MEXICO	13350	Highlands	3850		0	1210	2640
		Central High Plains	1210		0	0	1210
		Southern High Plains	4830	30	0	1140	3720
		Rio Grande	2900		1290	760	850
		Plateau		530	0	530	0
NORTH DAKOTA	4620	Dakotas	4470	150	0	0	4620
OKLAHOMA	1020	Central High Plains	1020		0	0	1020
SOUTH DAKOTA	4290	Dakotas	4280		0	0	4280
		Montana		10	0	0	10
TEXAS	15170	Central High Plains	2080		0	0	2080
		Southern High Plains	6560	220	0	0	6780
		Rio Grande	2200		0	0	2200
		Coastal Plain		4110	0	0	4110
UTAH	3370	Great Basin	3370		320	2620	430
WYOMING	680	Wyoming Basin		680	0	610	70
TOTAL	112130		94110	18020	6390	36140	64600

* Includes all private, state, and non-BLM, non-DoD federally owned lands.

DISTRIBUTION AND OWNERSHIP OF SUITABLE AREA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

TABLE 2.2-2

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STATE	TOTAL SUITABLE NM^2	INCLUSIVE CSP(S)	RECOMMENDED SUITABLE AREA (NONROCK)	LAND OWNERSHIP CONDITIONS		
				DoD AREA	BLM AREA	*OTHER (NM^2)
ARIZONA	14310	Highlands	3660	0	760	2900
		Great Basin	1990	0	940	1050
		Sonoran	8660	2080	3340	3240
CALIFORNIA	9160	Sonoran	8450	1340	5120	1990
		Great Basin	710	0	640	70
COLORADO	4920	Central High Plains	4920	0	0	4920
IDAHO	520	Great Basin	520	0	170	350
KANSAS	4470	Central High Plains	4470	0	0	4470
NEBRASKA	2630	Central High Plains	2630	0	0	2630
NEVADA	19450	Great Basin	19090	1360	15990	1740
		Sonoran	360	0	350	10
NEW MEXICO	12790	Highlands	3850	0	1210	2640
		Central High Plains	1210	0	0	1210
		Southern High Plains	4830	0	1130	3700
		Rio Grande	2900	1290	760	850
OKLAHOMA	1020	Central High Plains	1020	0	0	1020
TEXAS	10840	Central High Plains	2080	0	0	2080
		Southern High Plains	6560	0	0	6560
		Rio Grande	2200	0	0	2200
UTAH	3370	Great Basin	3370	320	2620	430
TOTAL	83480		83480	6390	33030	44060

* Includes all private, state, and non-BLM, non-DoD federally owned lands.

DISTRIBUTION AND OWNERSHIP OF RECOMMENDED SUITABLE AREA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE 2.2-3

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2.3 FINE SCREENING

2.3.1 Evaluation Criteria

Fine Screening evaluation considered that it may be necessary to maintain security control, not only of the siting area, but also adjacent areas that may provide access. The Fine Screening criteria were derived from requirements obtained from working groups such as S & H, communications, transportation, facilities, and systems engineering. The requirements represent geotechnical values best suiting the needs of the particular study group. In general, exceeding the values or constraints provided would result in significantly increased costs or complexity to system deployment.

2.3.2 Objectives and Additional Criteria

The objective of the Fine Screening study was to obtain basic data that may limit the suitability and/or the probability of being able to use the lands to site the MX system. This screening did not result in any major land exclusions. Rather, it demonstrated the amount of fragmentation of suitable parcels that occurred by identifying restricted-use areas due to utility corridors (roads, energy or water conveyance systems, etc.). The investigation consisted of a literature search of readily available, pertinent state and federal level energy resource and distribution, and land-use publications.

It is difficult to obtain comprehensive, useable data relating to the communication line criterion, so its application to the Fine Screening study was necessarily postponed. Most of the

FNI REFERENCE NUMBER	CRITERIA	DEFINITIONS
FS-1	Military Bases/Missile Sites	1 nm (nautical mile) from boundaries of all military bases and missile sites
FS-2	Electrical Transmission Lines	1 nm from boundaries of all major buried and surface electrical transmission lines (≥115 kv)
FS-3	Communication Lines	1 nm from boundaries of all major buried and surface communication lines
FS-4	Oil and Gas Pipelines	1 nm from boundaries of all major buried and surface oil and gas pipelines (>4 inch diameter)
FS-5	Mineral Deposits, Mining Distribution areas, Oil and Gas Fields	1 nm from boundaries of all economically important mineral deposits, mining distribution, and oil and gas fields
FS-6	Highways, Railroads	1 nm from boundaries of all major state and federal paved highways, and railroads
FS-7	Cultural Land Use	1 nm from boundaries of all state and federal parks, monuments, forests, grasslands; historic sites; game preserves and refuges; Indian reservations, and public lands set aside to preserve areas with unique recreational, historical, and natural values
FS-8	International Borders	5 nm from boundaries of international borders
FS-9	Communities	1 nm from boundaries of all communities with populations less than 5,000
FS-10	Large Energy/Water Projects	1 nm from the boundaries of all large energy or water conveyance projects (eg. known geothermal resource areas/major canals and aqueducts)

FINE SCREENING
RESTRICTED USE CRITERIA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE 2.3-1

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newly applied geotechnical information was in the form of field observations gained during the geotechnical Characterization studies (Section 3.0). Specific applied Fine Screening criteria are listed in Table 2.3-1.

2.3.3 Process

Base maps of scale 1:500,000 were produced from U.S. Geological Survey two-degree sheets. Each base map includes a Candidate Siting Province. Registered mylar overlays, placed over the base maps, were used to compile the Fine Screening criteria.

A quality assurance concept was initiated to provide a check system for plotting electrical transmission lines and oil/gas pipelines. State level maps at scales of 1:500,000 to 1:1,000,000 were used to plot criteria. Regional maps of larger portions of the United States (1:3,500,000) were used to check the physical presence, ownership, and power capacities of the displayed criteria.

2.3.4 Results

The Fine Screening study identified general cultural characteristics of each CSP prior to geotechnical ranking. The Fine Screening restricted-use criteria reduced the suitable area (83,480 nm^2; 286,336 km^2) by approximately 30 percent to 56,500 nm^2 (194,069 km^2). This reduction is not an exclusion rather, it defines areas that would not be suitable for MX siting should an area (vs point) controlled security system be imposed. Table 2.3-2 summarizes the distribution and ownership of the suitable area remaining after Fine Screening. The areal

STATE	TOTAL SUITABLE NM 2	INCLUSIVE CSP(S)	SUITABLE AREA (NM2)	LAND OWNERSHIP CONDITIONS		
				DoD AREA (NM2)	BLM AREA (NM2)	* OTHER (NM2)
ARIZONA	8450	Highlands	1900	0	420	1480
		Great Basin	1250	0	690	560
		Sonoran	5300	1800	1990	1510
CALIFORNIA	7000	Sonoran	6400	1290	4180	930
		Great Basin	600	0	560	40
COLORADO	3350	Central High Plains	3350	0	0	3350
IDAHO	350	Great Basin	350	0	120	230
KANSAS	2900	Central High Plains	2900	0	0	2900
NEBRASKA	1700	Central High Plains	1700	(0.016)**	0	1700
NEVADA	14650	Great Basin	14500	1220	12100	1180
		Sonoran	150	0	140	10
NEW MEXICO	8500	Highlands	2700	0	1170	1530
		Central High Plains	900	0	0	900
		Southern High Plains	2950	0	490	2460
		Rio Grande	1950	1050	500	400
OKLAHOMA	500	Central High Plains	500	0	0	500
TEXAS	6300	Central High Plains	1200	0	0	1200
		Southern High Plains	3550	0	0	3550
		Rio Grande	1550	0	0	1550
UTAH	2800	Great Basin	2800	300	2120	380
TOTAL	56500		56500	5660	24480	26360

* Includes all private, state, and non-BLM, non-DoD federally owned lands.

** 14 acres, Minuteman Missile sites.

DISTRIBUTION AND OWNERSHIP OF SUITABLE AREA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE 2.3-2

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distribution resulting from Fine Screenig is shown in Drawing 2.3-A.

Each CSP incurred different restrictions of suitable area as a consequence of the Fine Screening study. The total effect that the criteria had on reducing suitable area in each CSP is as follows: Great Basin, 24 percent; Sonoran, 32 percent; Highlands, 39 percent; Rio Grande, 31 percent; Southern High Plains, 43 percent; Central High Plains, 38 percent. The suitable area defined by Fine Screening is that area remaining suitable for MX siting after the application of the criteria.

2.3.5 Vertical Shelter Siting Considerations

The screening process through Fine Screening was designed to identify suitable areas in which all MX concepts then being considered could be deployed. In spring 1978, the vertical shelter concept (nominal construction depth 150 feet; 46 m) was emphasized. Although the suitable siting areas were generally acceptable for the siting vertical shelters, concern was expressed about the limitation of the original criteria whereby areas with rock and water depths between 50 (15 m) and 150 feet (46 m) were still considered suitable. Although the absence of rock and water is a preferred construction condition, the presence of excavatable rock and water within the construction zone was demonstrated to cause only small increases in the construction costs when compared to load costs. Hard rock, requiring blasting, does have a significant impact on costs; however, these conditions generally occur in very limited portions of the siting areas.

A limited study (literature only) was initiated in May 1978, to determine the percent of suitable area, as defined from Coarse and Intermediate Screening that have hard rock and water within 150 feet (46 m). Drawing 2.3-B and the following items describe the results of this study:

1. The Central and Southern High Plains CSPs were the most affected, with 60 percent of the suitable area having a high likelihood of water or rock materials within the upper 150 feet (46 m) of the ground surface.

2. Both the Rio Grande and Highlands CSP's had significant area reductions (25 and 40 percent, respectively) which tended to further fragment the individual parcels.

3. The CSP least affected was the Sonoran, with less than ten percent of the CSP having known rock and water within 150 feet (46 m) of the surface.

4. A significant portion (40 percent) of the Great Basin's CSP suitable area has water and rock within 150 feet (46 m) of the surface, however, most of the area affected was in northern Nevada.

Based upon the nature of the limited study, rock within 150 feet (46 m) was only determined with reasonable confidence in the Central and Southern High Plains CSPs, where the subsurface rock conditions are well known and somewhat predictable. Depth to rock, particularly within 150 to 300 feet (46 to 92 m) is virtually undocumented and very difficult to predict in all

remaining CSPs. However, it is estimated that their suitable area could be reduced by as much as an additional 10 to 20 percent. An important part of the verification program will be to obtain adequate information about depth to hard rodk.

3.0 GEOTECHNICAL CHARACTERIZATION STUDIES

3.1 CONCEPT AND SCOPE

3.1.1 Concept

Intermediate Screening indicated that existing data were not adequate in type or level of detail for follow-on geotechnical and geoenvironmental evaluations, screening, site selection and ranking studies. Therefore, the geotechnical Characterization studies were developed to provide a rapid, relatively inexpensive method of gathering specific data in small (<1000 nm^2), representative areas which could be selectively extrapolated within each CSP with a relatively high confidence level. Emphasis was placed on the collection of information allowing characterization of geological units with respect to the construction aspects of MX missile options. Data objectives for the Characterization studies were to obtain the following geotechnical and cultural information for subsequent evaluation and ranking studies, and support of MX subsystems development and design:

- Terrain conditions
- Suitability of surficial soils for use as road subgrade
- Excavatability of subsurface soils and stability of excavations
- Capacity of the soils to support loads of MX structures
- Depth to rock and water
- Availability of coarse and fine aggregates for concrete and road base course, and water for consumption and system construction

- o Land use
- o Cultural resources

Although the program originally emphasized data collection for the trench and horizontal shelter basing modes, the data were utilized for evaluation of the vertical shelter basing mode as well.

3.1.2 Scope

Characterization studies consisted of both field and office investigations. Prime characterization sites were investigated to provide maximum technical data within the allotted time frame and resources. Supplemental sites were located to areally extend presupposed conditions at the prime site or to better assess ranges of conditions within the CSP. Table 3.1-1 defines the generic elements of prime and supplemental characterization investigations.

District offices of the U.S. Bureau of Land Management were contacted for access to characterization sites in the Great Basin CSP, and portions of the Rio Grande, Highlands and Sonoran CSPs. Access for the remaining sites was arranged through district offices of the U. S. Army Corps of Engineers.

Prior to initiating any field work, an archeological and environmental inspection was conducted at each site to ensure minimal impact to the local environment and to avoid damage to archeologic and historic sites. To further minimize potential impacts, all field activities were performed adjacent to existing roads, road rights-of-way or other previously disturbed areas.

PRIME CHARACTERIZATION SITES

ACTIVITIES	SITES*
ENGINEERING GEOLOGY PROGRAM:	∇*Dry Lake Valley NV
o Site geologic mapping	∇*Ralston Valley NV
o Reconnaissance survey of adjacent areas	*Sacramento Valley AZ
o Review of satellite imagery	*Mojave CA
SOILS ENGINEERING PROGRAM:	*Ranegras Plain AZ
o 1 to 5 300-foot borings	*Luke AZ
o 2 to 5 100-foot borings	*San Simon AZ
o 8 to 15 50-foot borings	∇*Jornada del Muerto NM
o 6 to 18 backhoe trenches (10 to 18 feet deep)	Roswell NM
o Laboratory testing	Muleshoe TX
GEOPHYSICAL PROGRAM:	Cimarron TX
o 14 to 21 seismic refraction lines (for material properties)	Scott City NB
o 12 to 20 electrical resistivity surveys (for soil conductivity)	Sterling CO
o Gravity survey*	
o Downhole seismic velocity measurements ∇	

*Selected prime site-gravity survey

SUPPLEMENTAL CHARACTERIZATION SITES

ACTIVITIES	SITES*
ENGINEERING GEOLOGY PROGRAM:	+Monitor Valley NV
o Site geologic mapping	+Ione-Smith Valley NV
o Reconnaissance survey of adjacent areas	Aguila AZ
o Review of satellite imagery	Santa Cruz AZ
SOILS ENGINEERING PROGRAM:	Mimbres Basin NM
o One 100-foot boring	Salt Basin TX
o 4 to 10 50-foot borings	Pecos TX
o Laboratory testing	Hobbs TX
GEOPHYSICAL PROGRAM:	Artesia NM
o 7 to 13 seismic refraction lines (for material properties)	Deaf Smith TX
o 6 to 13 electrical resistivity surveys (for soil conductivity)	Beaver TX
	Dodge City KS
	Kiowa CO

+Access obtained but program cancelled due to adverse weather.

GEOTECHNICAL ACTIVITIES CHARACTERIZATION PROGRAM

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE 3.1-1

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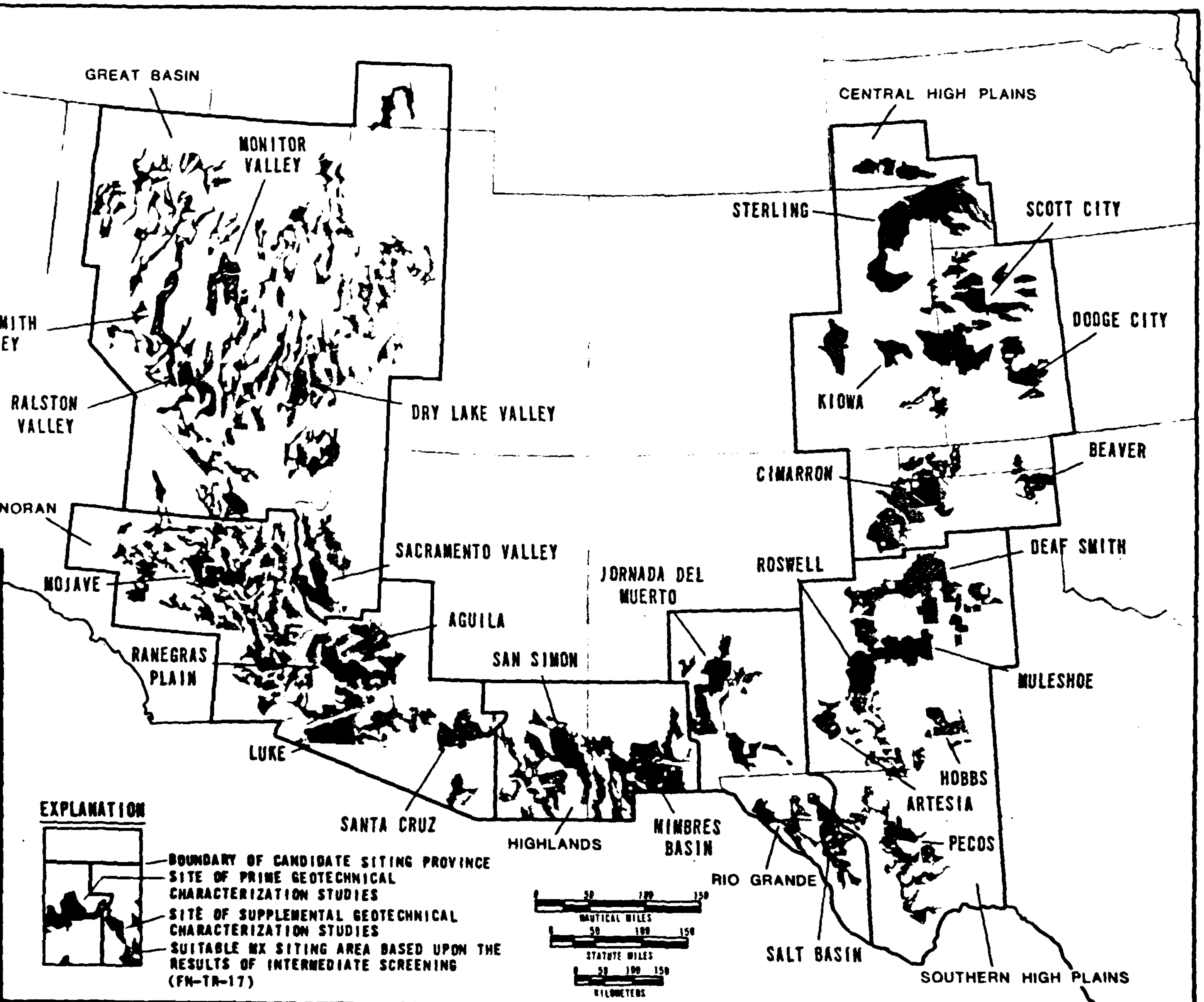
3.2 SELECTION OF CHARACTERIZATION SITES

Twenty-six characteriztion sites were selected (Figure 3.2-1) representing a total investigated area of less than 15 percent of all suitable area in the six CSPs. These sites were selected because they best reflected the known geologic, geomorphic and geoenvironmental setting of the CSP. This selection process was begun by delineating geotechnically similar areas within each CSP that had similar depositional and geologic histories, rock and water depths, and tectonic settings. Once these areas had been identified, non-geotechnical factors were applied to delineate the actual characterization site boundaries. These non-geotechnical factors included:

- Availability of topographic maps and aerial photographs
- Minimal study area size (150 to 250 nm^2; 500 to 850 km^2)
- Proximity to support facilities for field crews
- Accessibility
- Current land use and environmental impact of the proposed studies

Results of studies performed at individual prime characterization sites are presented in the following sections. These sites were selected to serve as examples of conditions present in a large portion of each CSP.



GEOTECHNICAL CHARACTERIZATION
STUDY AREA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
3.2-1

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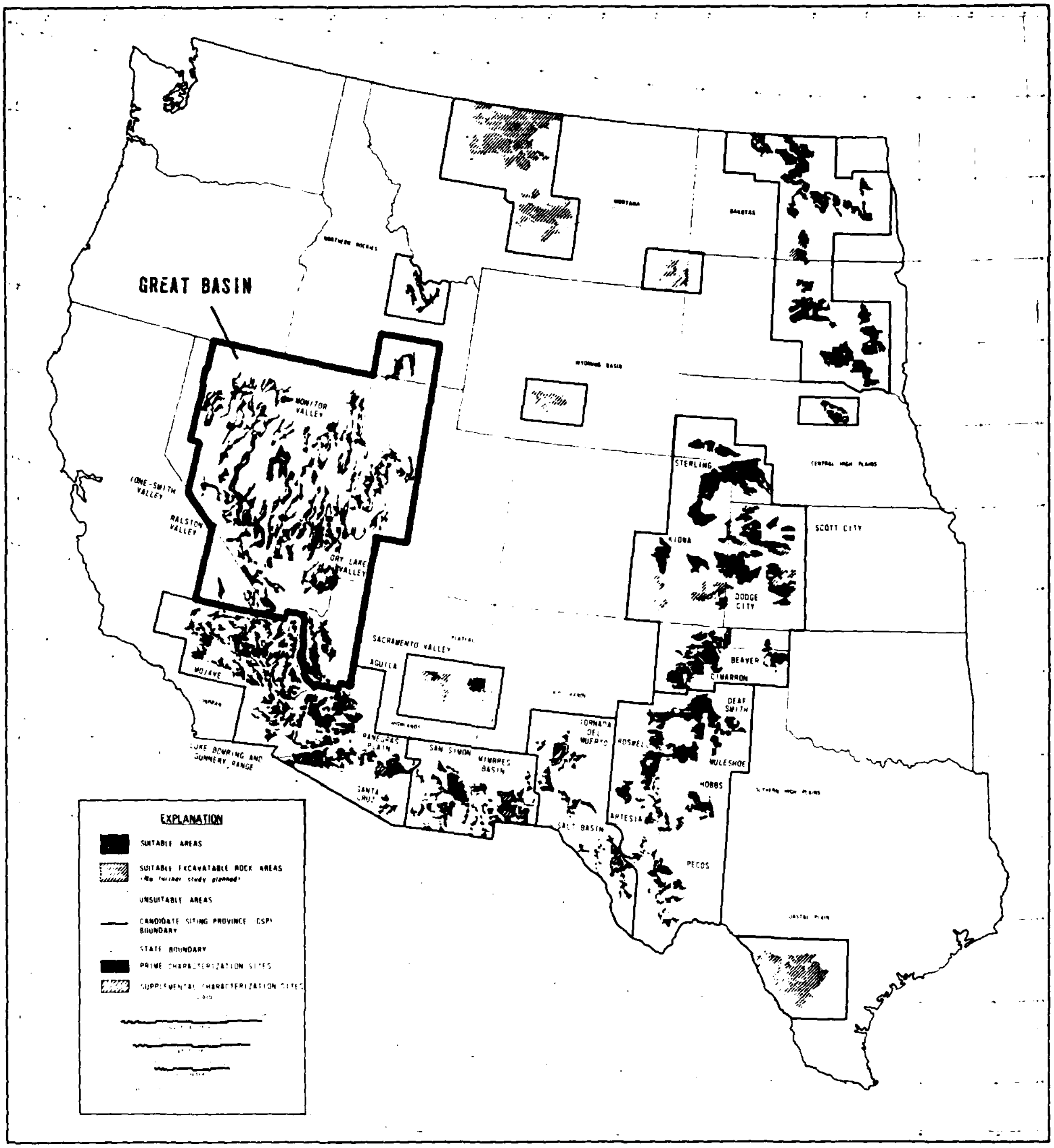
3.3 DRY LAKE VALLEY: GREAT BASIN CSP

The Great Basin CSP lies almost entirely within the Great Basin section of the Basin and Range physiographic province and includes most of Nevada as well as portions of western Utah, northern Arizona, southeastern California and southern Idaho (Figure 3.3-1). The majority of suitable area is federally administered (BLM, 81%; DoD, 7%), with remaining area either privately owned (10%) or state controlled (2%). Approximately 89 percent of the suitable area is used as rangeland, with four percent used for farming and seven percent for military operations.

The CSP is characterized by northeast to northwest trending elongate mountain ranges with intervening valleys that possess a variety of geologic and engineering conditions. Five sites were selected (Figure 3.3-2) to characterize geotechnical conditions within the CSP based upon a review of regional geologic and engineering literature. Results of the Dry Lake Valley investigation are presented to provide a sampling of the geotechnical conditons within the CSP, particularly those present in central Nevada.

The Dry Lake site covers an area of 251 nm^2 (861 km^2) in central Lincoln County Nevada. The site is bounded by mountain ranges on the east, north, and west, and is open to Delamar Valley on the south. Field activities for the characterization study are identified in Figure 3.3-3. The scope of both the field and laboratory activities is presented in Table 3.3-1.



LOCATION OF GREAT BASIN CSP

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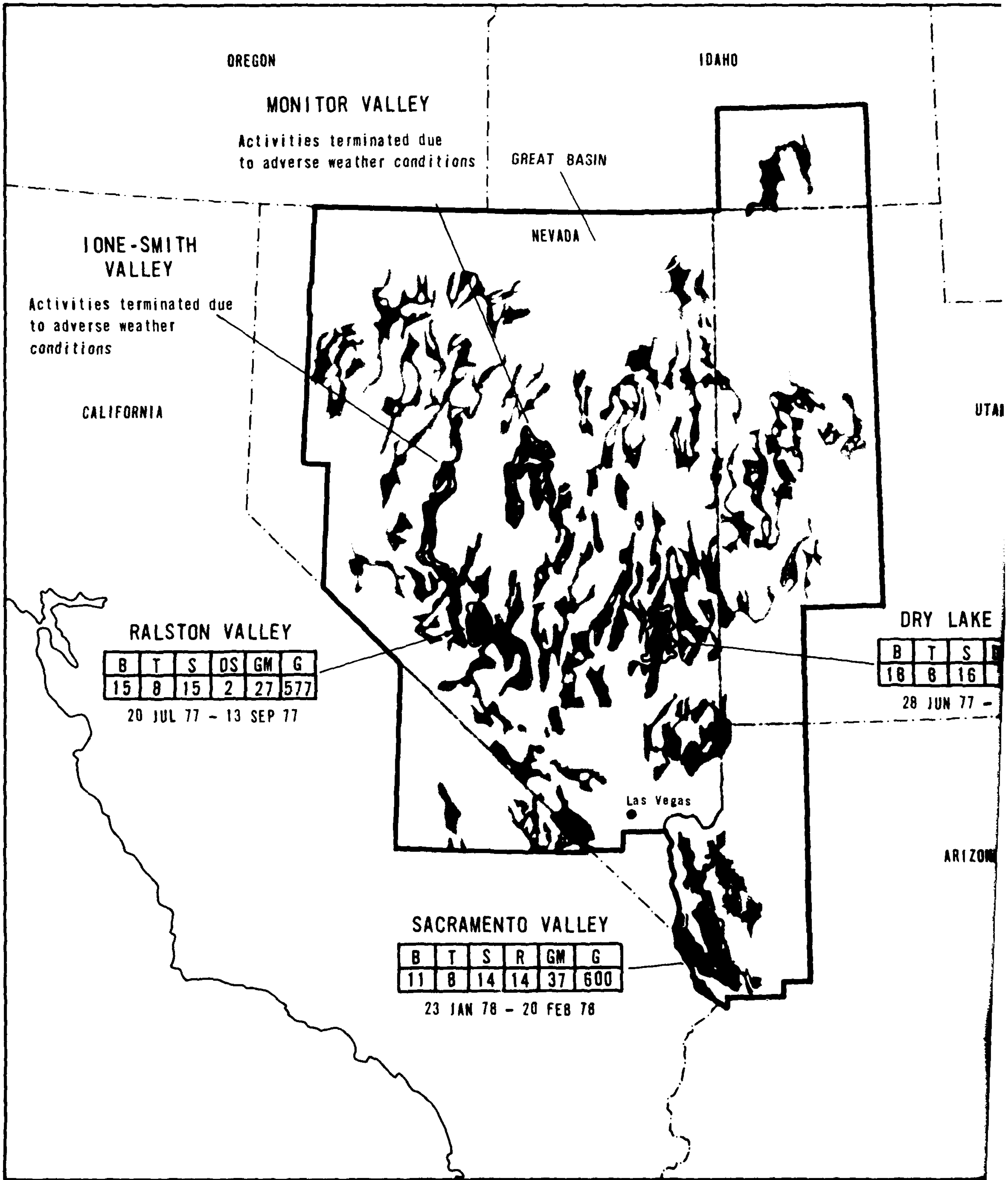
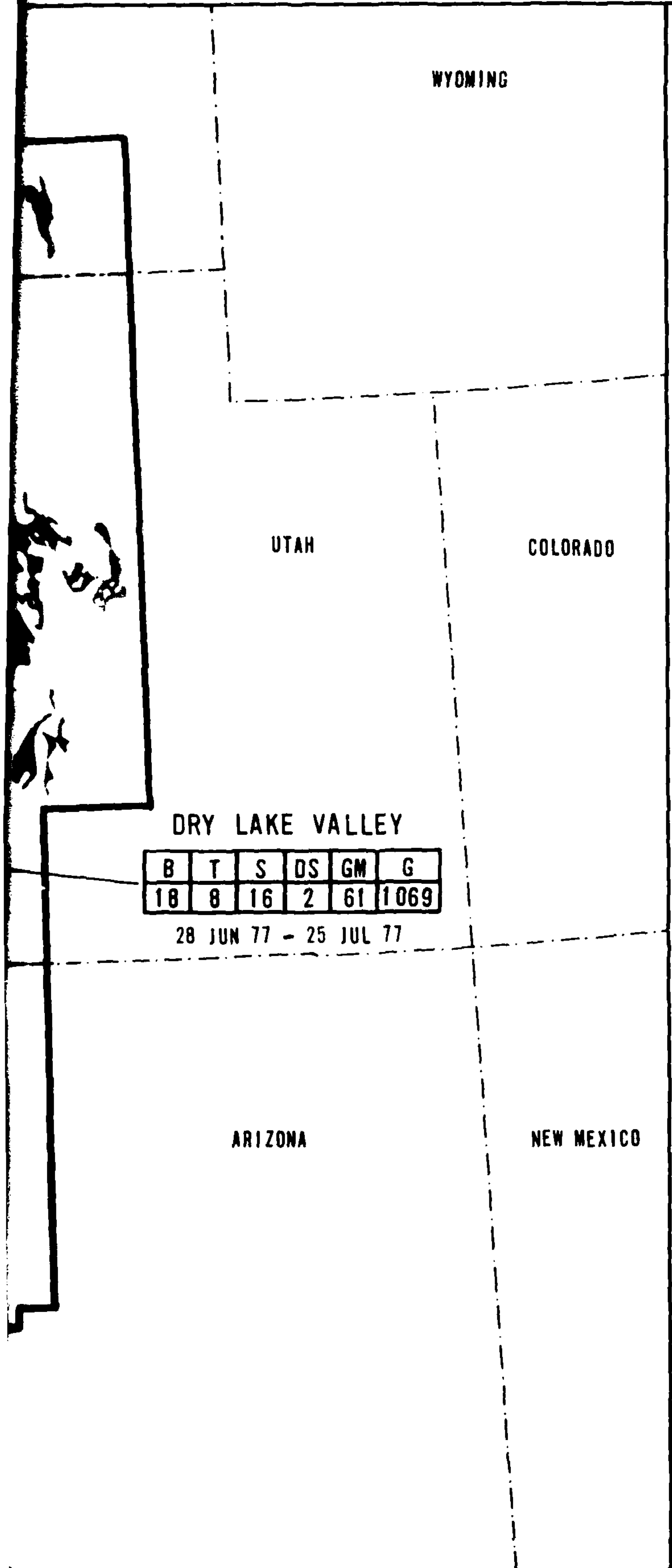
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE 3.3-1

FUGRO NATIONAL, INC.


OREGON
IDAHO
MONITOR VALLEY
Activities terminated due
to adverse weather conditions
GREAT BASIN
NEVADA
IONE-SMITH
VALLEY
Activities terminated due
to adverse weather
conditions
CALIFORNIA
UTA
RALSTON VALLEY
B T S DS GM G
15 8 15 2 27 577
20 JUL 77 - 13 SEP 77
DRY LAKE
B T S
18 8 16
28 JUN 77 -
Las Vegas
ARIZO
SACRAMENTO VALLEY
B T S R GM G
11 8 14 14 37 600
23 JAN 78 - 20 FEB 78



EXPLANATION

ACTIVITIES

- B - BORINGS
- T - TRENCHES
- S - SHALLOW SEISMIC REFRACTION LINES
- R - ELECTRICAL RESISTIVITY LINES
- DS - DEEP SEISMIC REFRACTION LINES
- GM - GEOLOGIC RECON MAPPING STATIONS
- G - GRAVITY STATIONS

B	T	— Activity
17	18	— Quantity of each activity

SUITABLE AREA

PRIME SITE

SUPPLEMENTAL SITE

0 50 100 150 200
NAUTICAL MILES

0 50 100 150 200
STATUTE MILES

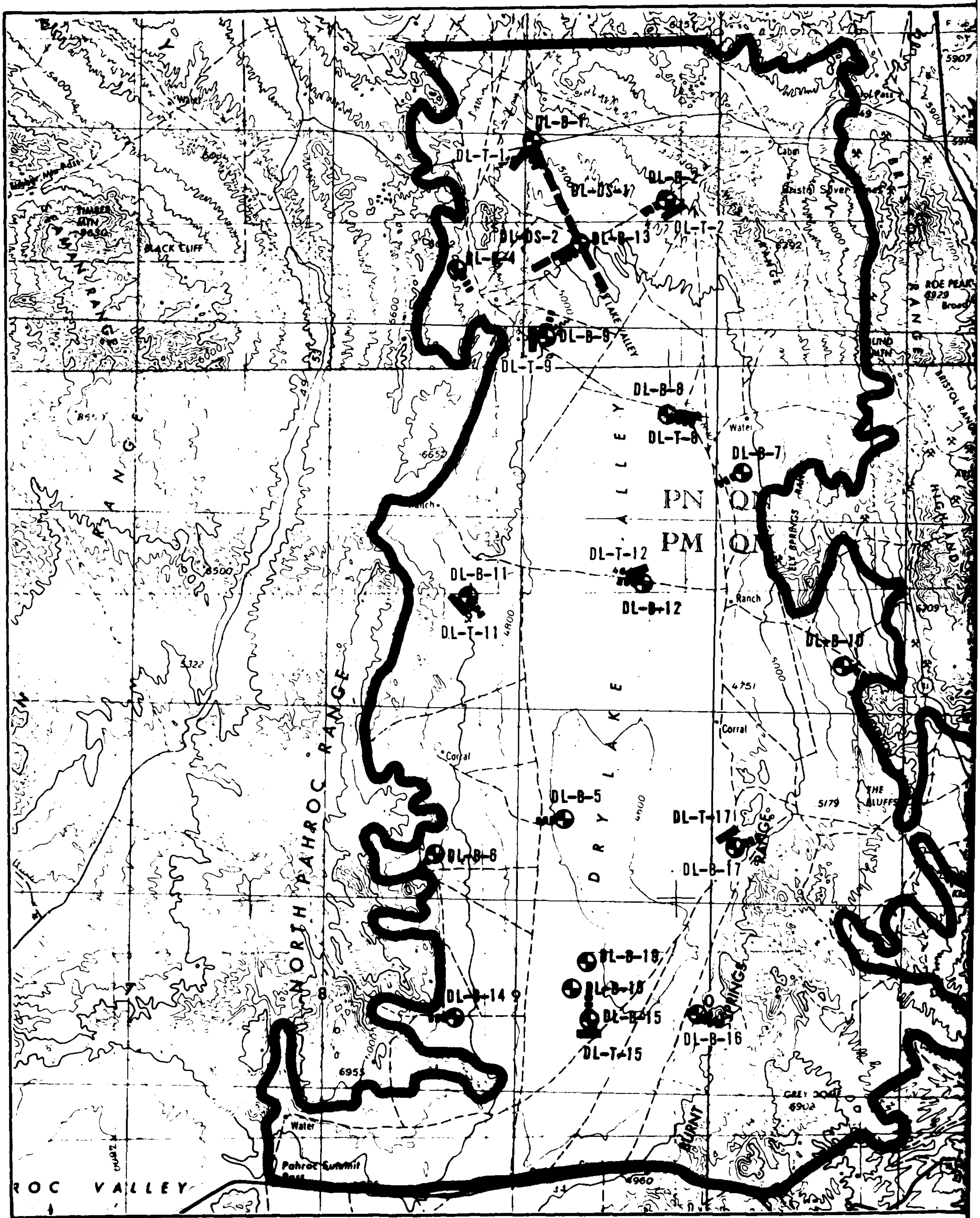
0 50 100 150 200
KILOMETERS

CHARACTERIZATION SITES
AND FIELD ACTIVITIES
GREAT BASIN CSP

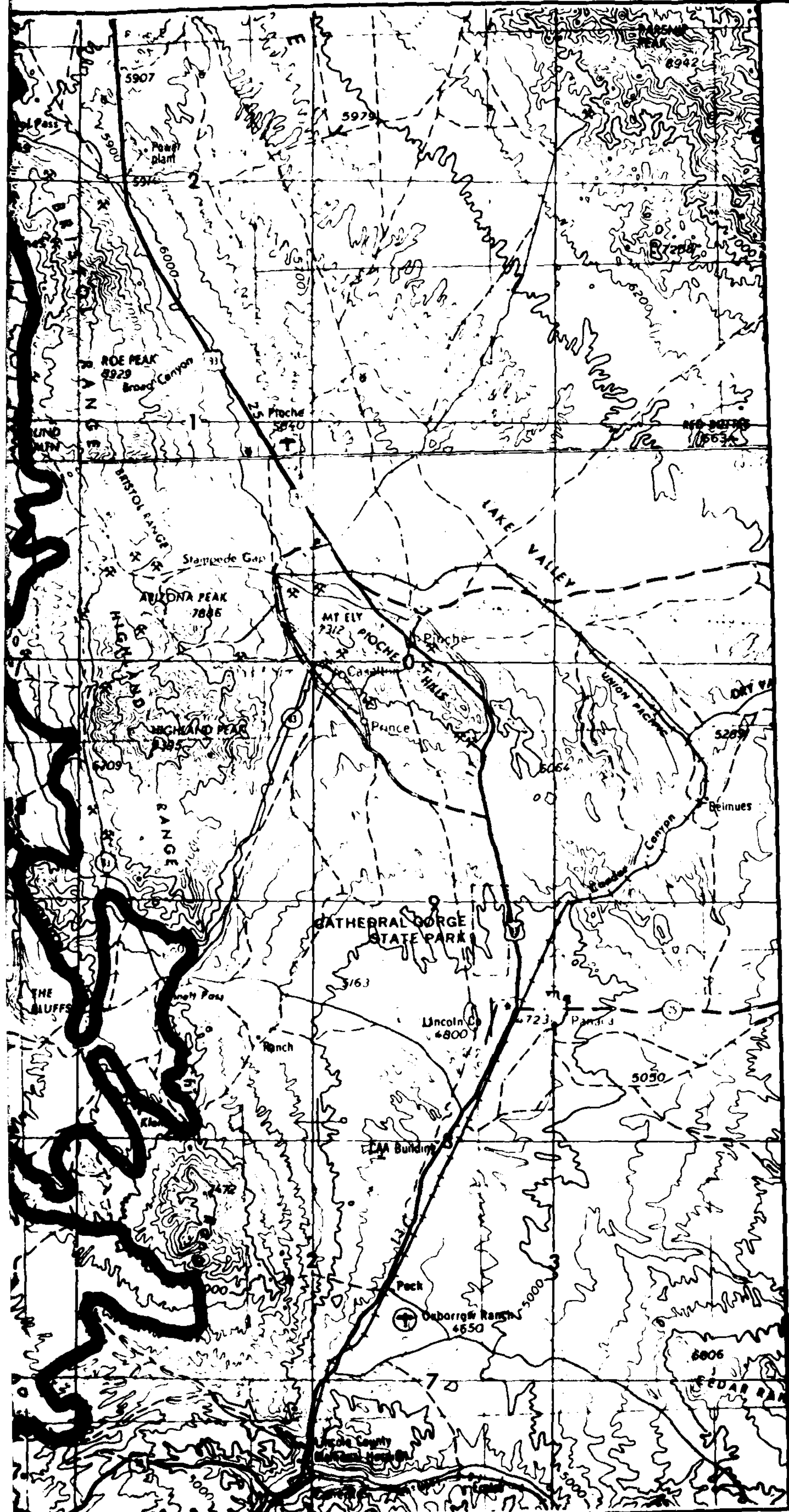
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.3-2

FUGRO NATIONAL, INC.



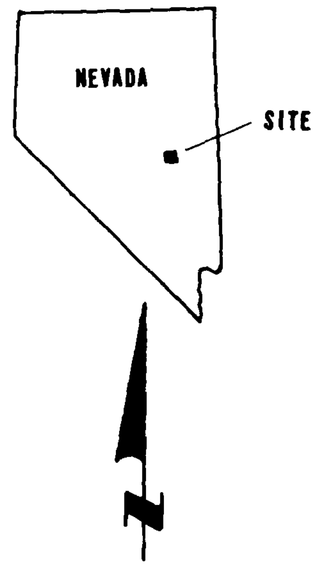
DL-B-1
DL-T-1
DL-DS-1
DL-B-2
DL-T-2
DL-DS-2
DL-B-13
DL-B-4
DL-B-9
DL-T-9
DL-B-8
DL-T-8
DL-B-7
PN
PM
DL-T-12
DL-B-12
DL-B-11
DL-T-11
DL-B-10
DL-B-5
DL-T-17
DL-B-17
DL-B-6
DL-B-18
DL-B-15
DL-T-15
DL-B-14
DL-B-16
TIMBER MTN
BLACK CLIFF
NORTH PAHROC RANGE
DRY LAKE VALLEY
ROE PEAK
THE BLUFFS
GREY DOME
Pahroc Summit Pass
ROC VALLEY
Water
Corral
Ranch
Cabin
ELK SPRINGS



EXPLANATION

- Boring
- Deep seismic refraction line
- Trench
- Seismic refraction line

SITE LOCATION



1:250,000
1" = 3.2 Nautical Miles
(APPROXIMATE)

ACTIVITY LOCATION MAP
DRY LAKE VALLEY, NEVADA
GREAT BASIN CSP

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FIGURE 3.3-3

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GEOLOGY AND GEOPHYSICS

TYPE OF ACTIVITY	NUMBER OF ACTIVITIES
Geological mapping stations	61
Shallow refraction	16
Deep refraction	2
Downhole velocity	2
Gravity survey	1069

ENGINEERING

NUMBER OF BORINGS	DEPTH FEET(METERS)
1	20 (6)
3	50 (15)
8	100 (30)
5	300 (91)
1	450 (137)
NUMBER OF TRENCHES	**DEPTH FEET(METERS)**
1	16 (5)
7	18 (6)

ENGINEERING-LABORATORY TESTS

TYPE OF TEST	NUMBER OF TESTS
Moisture/density	362
Specific gravity	12
Sieve analysis	206
Hydrometer	99
Atterberg limits	121
Consolidation	4

TYPE OF TEST	NUMBER OF TESTS
Unconfined compression	13
Triaxial compression	10
Direct shear	4
Compaction	8
CBR	4
Chemical analysis	11

SCOPE OF FIELD AND LABORATORY ACTIVITIES
DRY LAKE VALLEY, NEVADA

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TABLE 3.3-1

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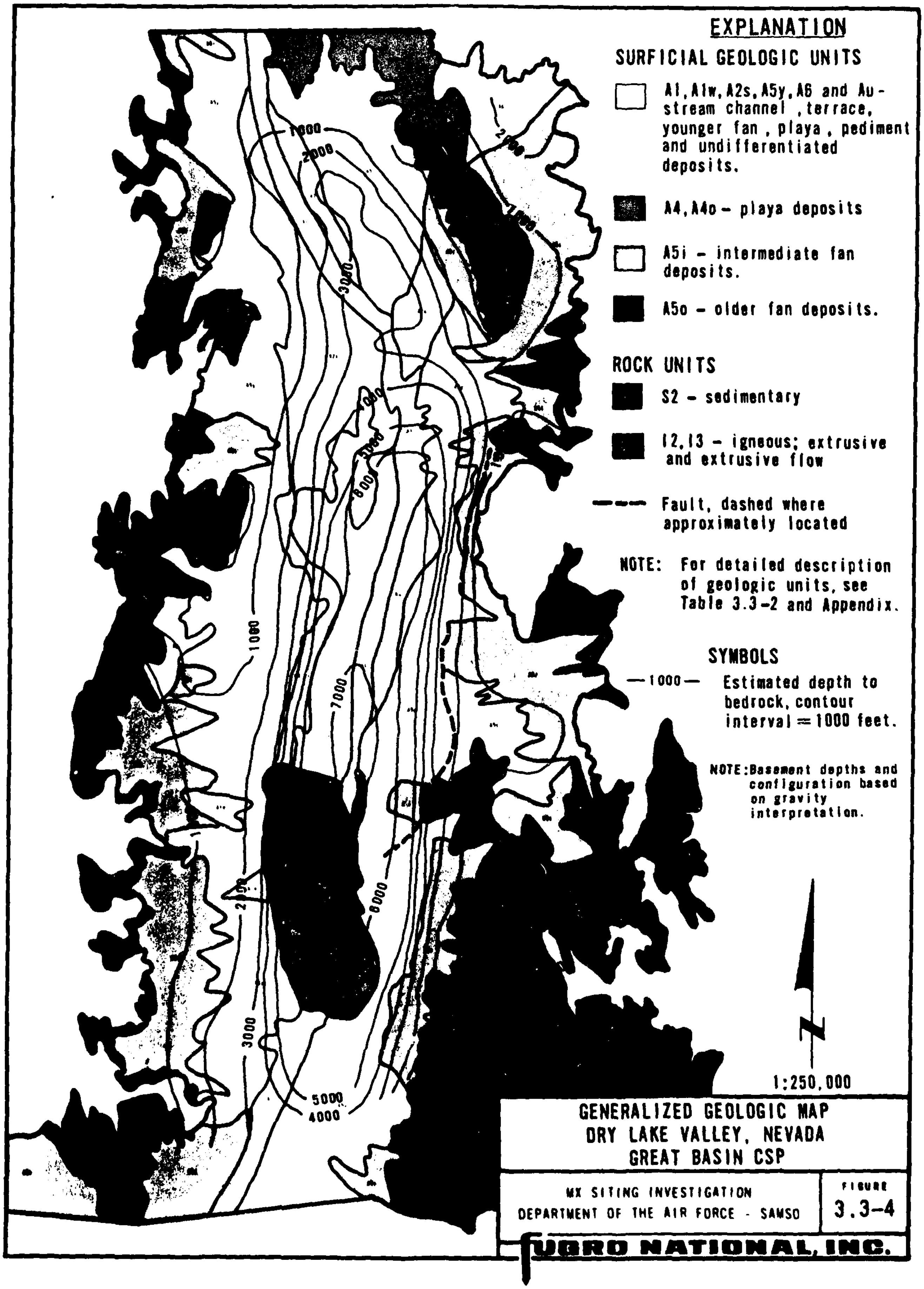
3.3.1 Surficial Geology and Terrain

Alluvial fan deposits of younger and intermediate age are the predominant surficial geologic units within the characterization site (Figure 3.3-4). The younger fan deposits cover approximately 42 percent of the area while the intermediate fan deposits cover 26 percent. Playa deposits cover approximately three percent of the surface. Although playa deposits do not represent a large percentage of the surface area, they are generally of great thickness and interfinger with alluvial deposits in the subsurface. Playa deposits are located in the valley centers with the alluvial deposits present between the playas and mountain fronts. The alluvial fan deposits are typically silty sand with gravel, ranging from sandy gravels near the mountain front to sandy silts near the playas. Playa deposits are generally clayey silts. These three units along with the remaining surficial units are described in Table 3.3-2.

Surface slopes and depths of drainage incision vary with geologic units, both generally increasing with relative age of the alluvial fan deposits (Table 3.3-2). Maximum surface slope (excluding older alluvial fan deposits) is ten percent with typical slopes of four percent. Maximum depths of incision (excluding older alluvial fan deposits) are 15 feet (5 m) with typical depths of five feet (1.5 m).

3.3.2 Subsurface Conditions

The composition of the soils with depth is illustrated by the soil profile shown in Figure 3.3-5. The gradation of these soils is similar to the surficial geologic units; however, the


EXPLANATION
SURFICIAL GEOLOGIC UNITS
A1, A1w, A2s, A5y, A6 and Au - stream channel, terrace, younger fan, playa, pediment and undifferentiated deposits.
A4, A4o - playa deposits
A5i - intermediate fan deposits.
A5o - older fan deposits.
ROCK UNITS
S2 - sedimentary
I2, I3 - igneous; extrusive and extrusive flow
Fault, dashed where approximately located
NOTE: For detailed description of geologic units, see Table 3.3-2 and Appendix.
SYMBOLS
—1000— Estimated depth to bedrock, contour interval = 1000 feet.
NOTE: Basement depths and configuration based on gravity interpretation.
1000
2000
3000
4000
5000
6000
7000
1:250,000
GENERALIZED GEOLOGIC MAP
DRY LAKE VALLEY, NEVADA
GREAT BASIN CSP
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO
FIGURE 3.3-4
FUGRO NATIONAL, INC.

ENGINEERING GEOLOGY UNIT (e)	GEOLOGIC AGE	THICKNESS FEET (METERS)	DESCRIPTIVE NAME(S)	USCS SYMBOL(S)	AREAL EXTENT (SITE)		GRA
					nm^2 (km^2)	PERCENT	
Undifferentiated Non-Rock Deposits (Au)	Quaternary-Tertiary	Unknown	Silty Sand with Gravel	SM	16 (55)	6	Poo
Fluvial Deposits (A1)	Holocene	Unknown	Silty Sand with Gravel	SM	24 (82)	10	Mode
Stream Terrace Deposits (A2s)	Holocene	Unknown	Silty Sand with Gravel	SM	16 (55)	6	Mode
Playa Deposits (A4)	Holocene	Unknown	Silty Clay Clayey Silt	CL, ML	11 (37)	4	
Older Playa and or Lacustrine Deposits (A4o)	Quaternary-Tertiary	Unknown	Clayey Silt	MH	5 (17)	2	
Younger Alluvial Fan Deposits (A5y)	Holocene	Unknown	Silty Sand with Gravel	SM	103 (353)	42	Mod
Intermediate Alluvial Fan Deposits (A5i)	Pleistocene	Unknown	Gravelly Silty Sand	SM	70 (241)	28	Mod we
Older Alluvial Fan Deposits (A5o)	Pleistocene	Unknown	Gravelly Silty Sand	SM	6 (21)	2	Mod we

NOTES:

(a) Mixed A1, A4 and A5 deposits.

(b) Includes three percent alluvial outwash deposits (A1w) which consist of mixed A1, A5y, and A5i deposits.

(c) Includes three percent mixed A4 and Au deposits; designated A4 Au on Figure 3.3-4.

(d) Includes two percent of area underlain by shallow rock, designated A6 on Figure 3.3-4.

(e) For generic description of geologic units, see Appendix.

S)	AREAL EXTENT (SITE)		PROPERTIES OF SURFACE MATERIALS					SURFACE MORPHOLOGY		NOTES
	nm^2 (km^2)	PERCENT	GRADATION	CEMENTATION	MAXIMUM GRAIN SIZE	PAVEMENT/ PATINA	STAGE OF CALICHE	SLOPE (PERCENT)	DRAINAGE DEPTHS FEET(METERS)	
	16 (55)	6	Poor-Well	Weak-Moderate	Cobble	None-Well/ None-Well	I-IV	<1-10	0-25 (0-8)	(a)
	24 (82)	10	Moderately well	None	Cobble	None/None	None-I	<1	0-1 (0-0.3)	(b)
	16 (55)	6	Moderately well	Weak	Cobble	Poor/ None-Poor	None-I	<1	0-15 (0-5)	
	11 (37)	4	Poor	None-Weak	Sand	None/None	None-I	<1	0-2 (0-0.6)	(c)
	5 (17)	2	Poor	Weak	Sand	None-Poor/ None-Poor	None-I	<1	0-5 (0-1.5)	
	103 (353)	42	Poor-Moderately well	None-Weak	Cobble	None-Poor/ None-Poor	None-I	0-5	0-5 (0-1.5)	
	70 (241)	28	Moderately well-Well	Weak-Moderate	Boulder	Poor-Well/ None-Fair	I-II	2-10	3-15 (1-5)	(d)
	6 (21)	2	Moderately well-Well	Weak-Moderate	Boulder	Poor-Well/ Poor-Well	III-IV	5-10	5-25 (0-8)	

A5y. and A5i deposits.

.3-4.

DESCRIPTION OF SURFICIAL GEOLOGIC UNITS DRY LAKE VALLEY, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

TABLE 3.3-2

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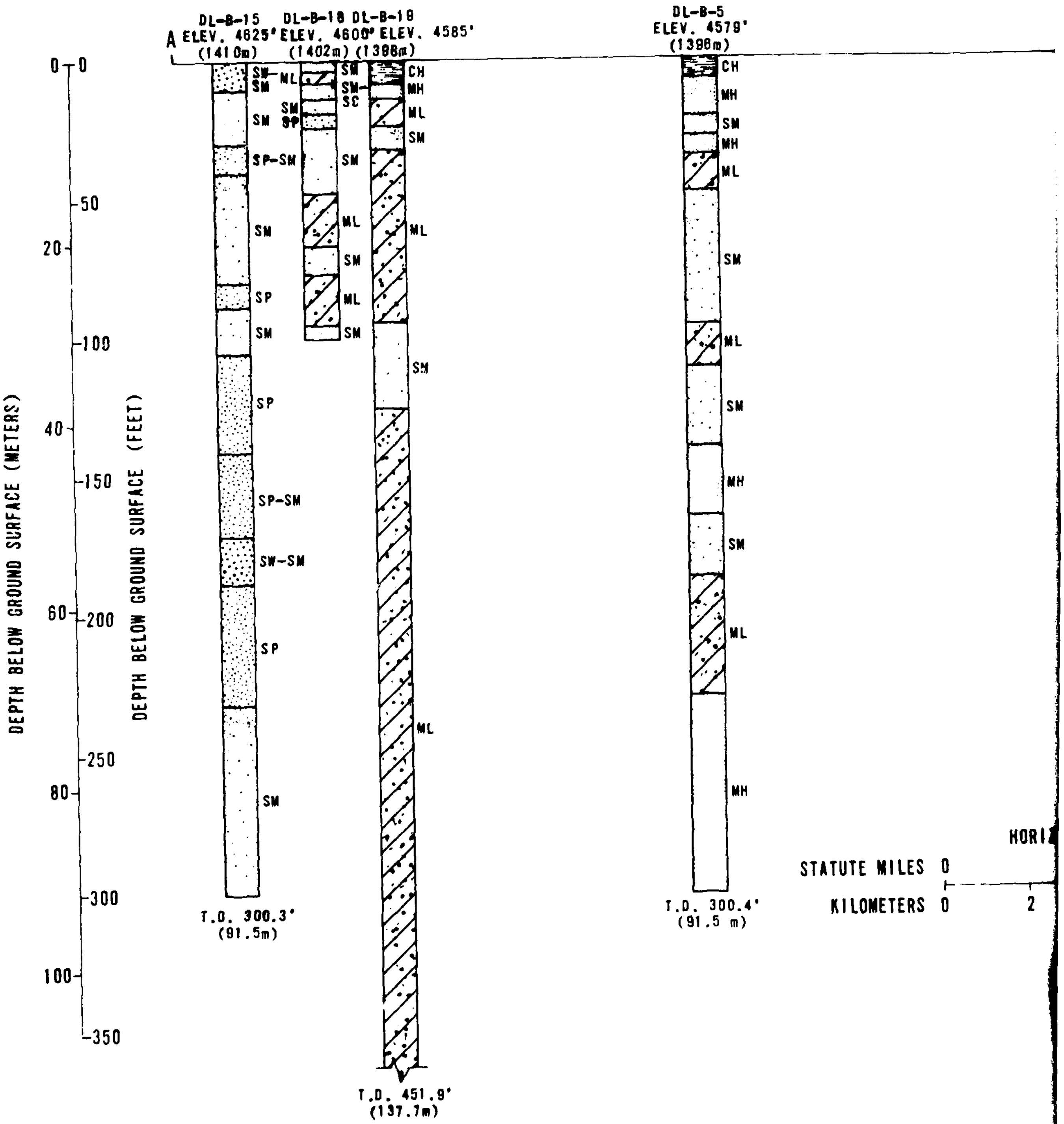
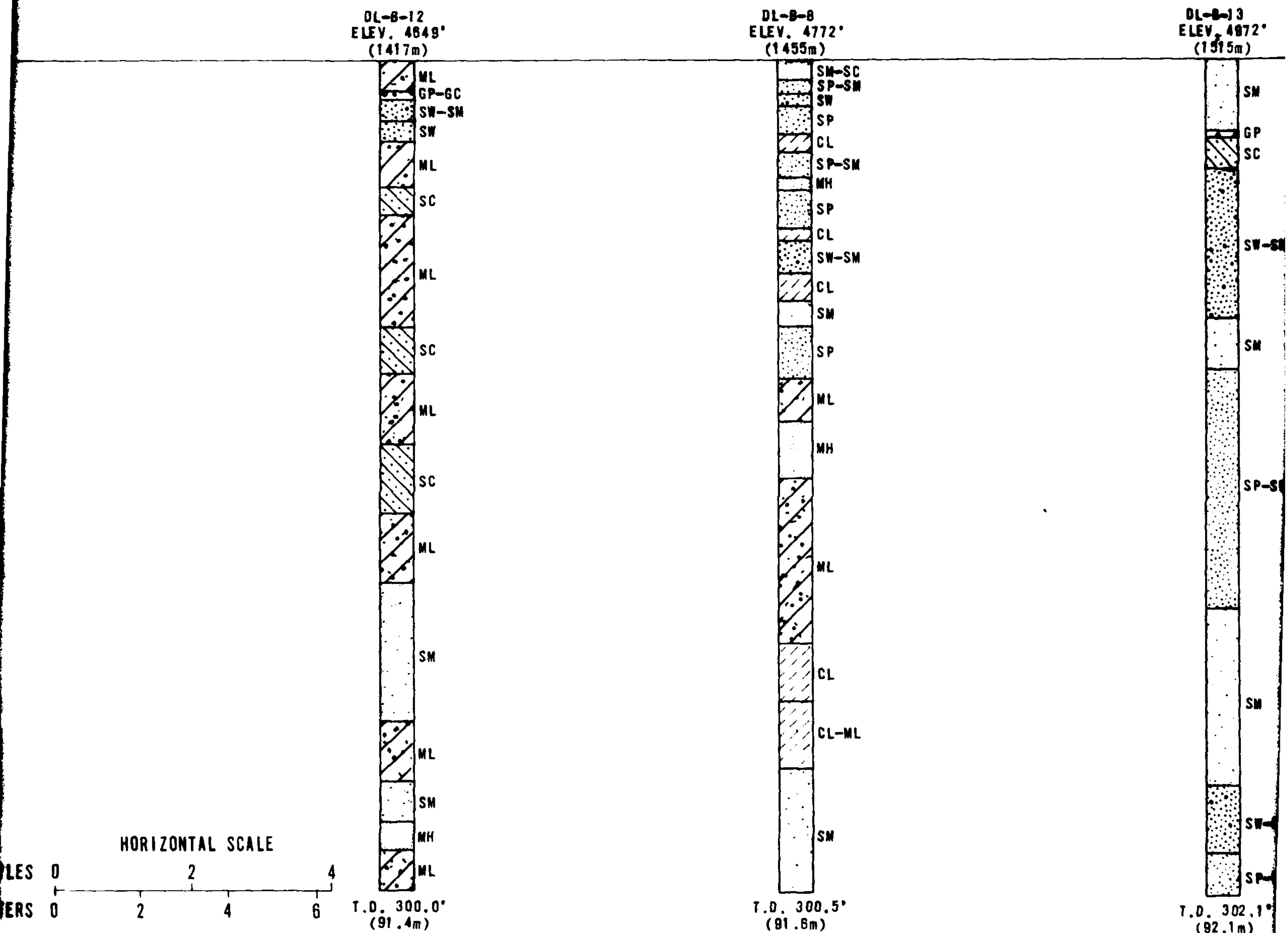
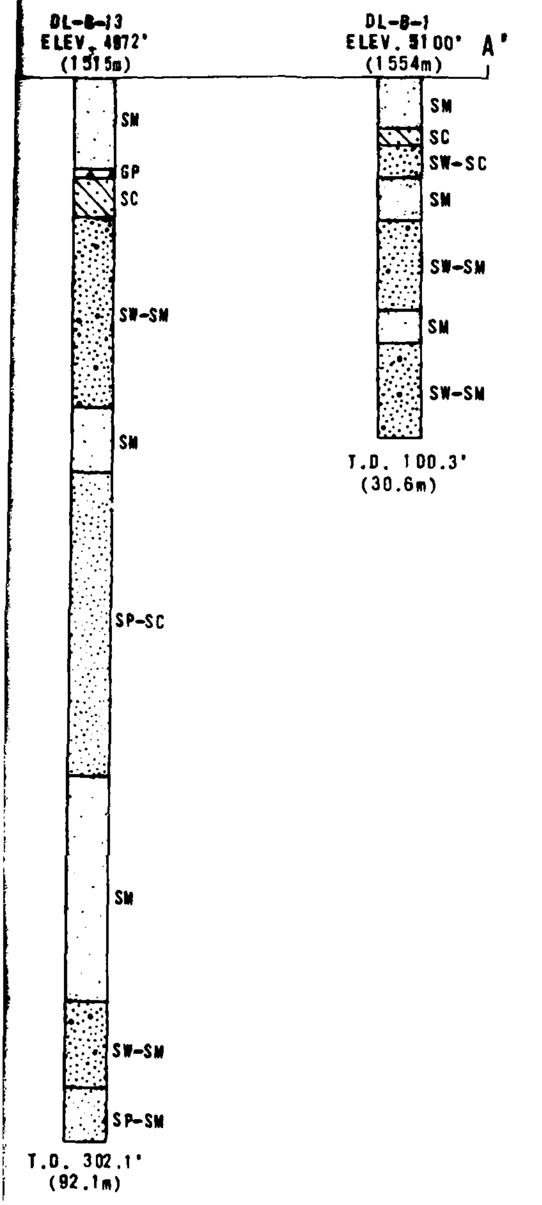
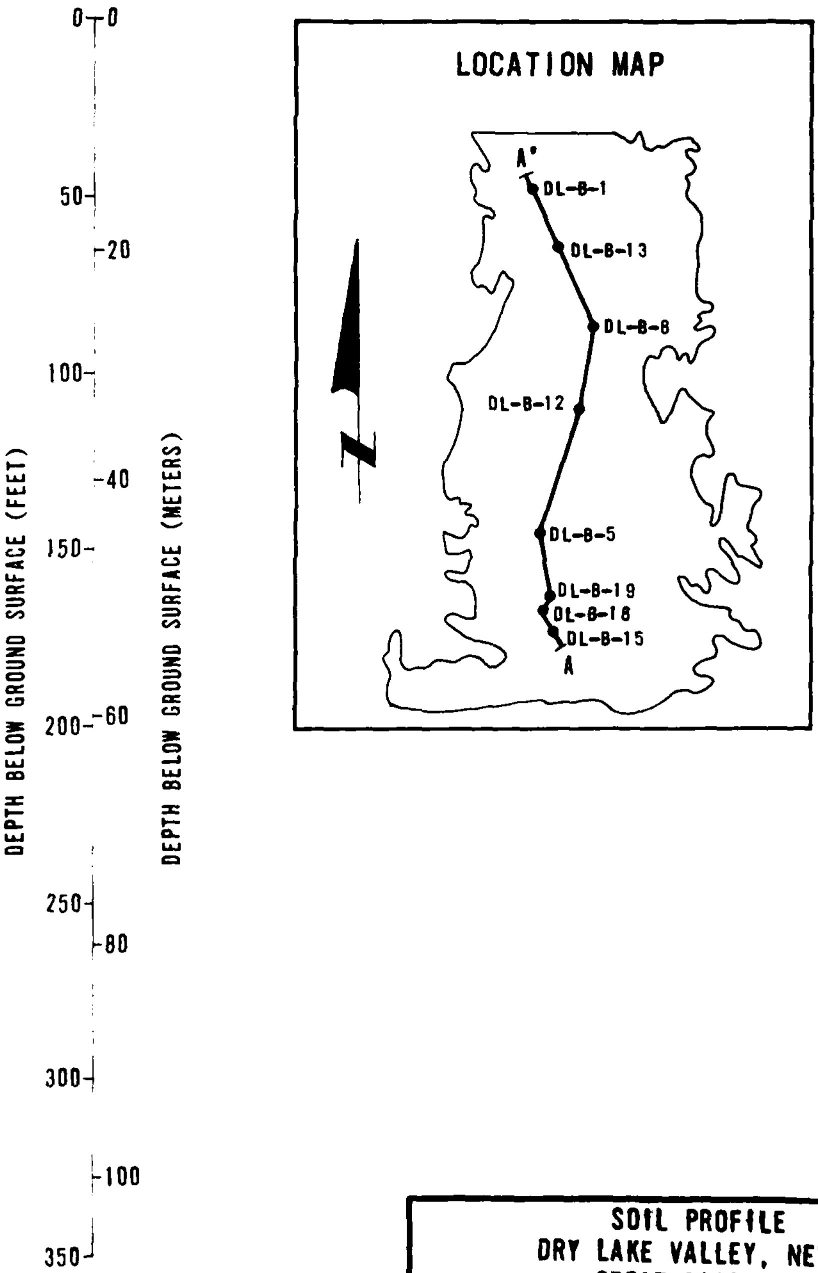


DL-B-15
ELEV. 4625'
(1410m)
DL-B-18
ELEV. 4600'
(1402m)
DL-B-19
ELEV. 4585'
(1398m)
DL-B-5
ELEV. 4579'
(1396m)
A
DEPTH BELOW GROUND SURFACE (METERS)
DEPTH BELOW GROUND SURFACE (FEET)
0
20
40
60
80
100
0
50
100
150
200
250
300
350
SW
SM
SM
SP-SM
SM
SP
SM
SP
SP-SM
SW-SM
SP
SM
ML
SM
SP
SM
ML
SM
ML
SM
SM
SM-SC
CH
MH
ML
SM
ML
SM
ML
CH
MH
SM
MH
ML
SM
ML
SM
MH
SM
ML
MH
T.D. 300.3'
(91.5m)
T.D. 451.9'
(137.7m)
T.D. 300.4'
(91.5 m)
HORI
STATUTE MILES 0
KILOMETERS 0
2



NOTES: 1. Ground surface elevations shown at locations of borings
2. T.D.= Total Depth
3. Soil types shown adjacent to soil column are based on U
(USCS) and are explained in the appendix





of borings are approximate

based on Unified Soil Classification System

SOIL PROFILE
DRY LAKE VALLEY, NEVADA
GREAT BASIN CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE
3.3-5

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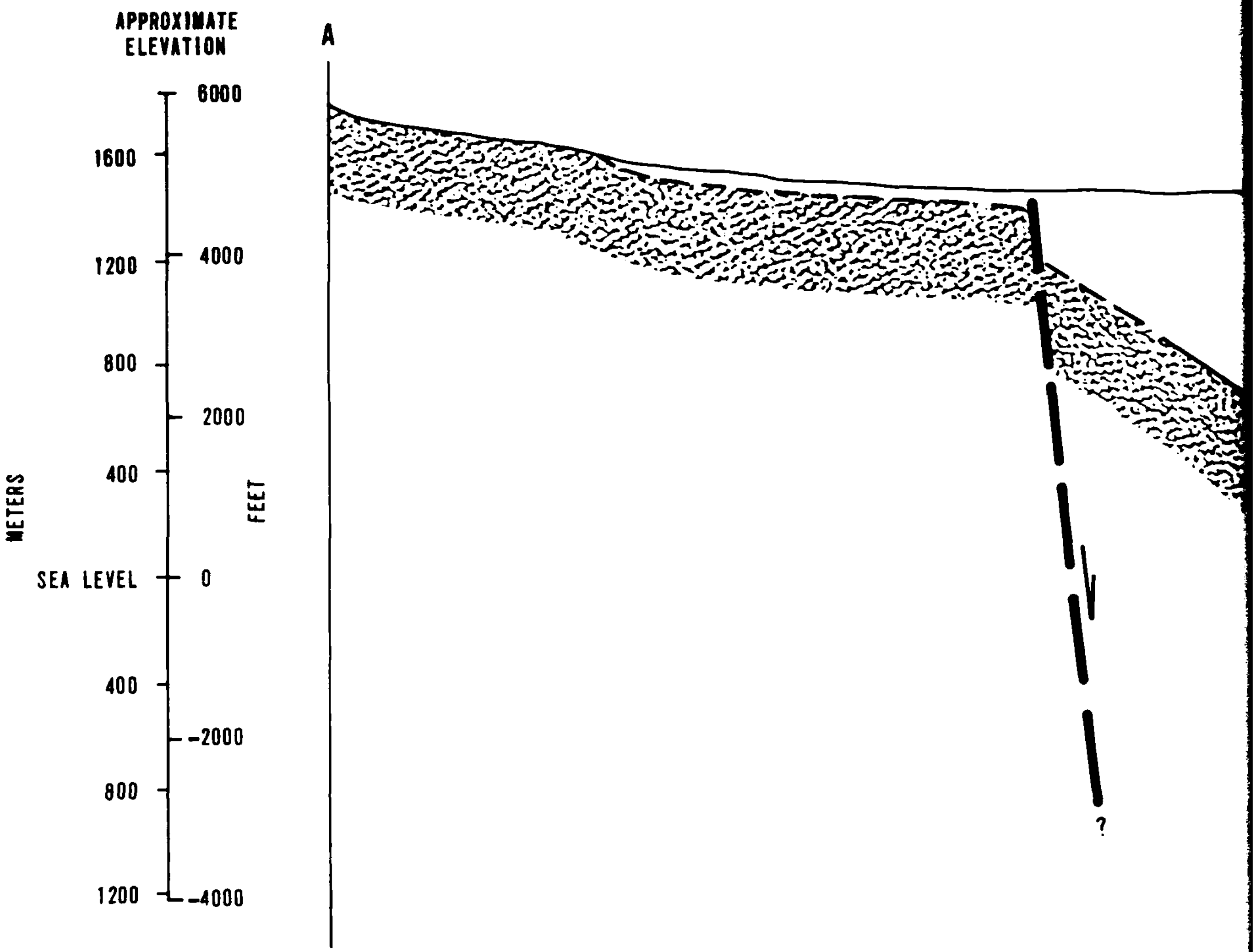
profile indicates that coarse and fine-grained soils are interbedded.

Geophysical investigations indicate shallow rock near the mountain fronts, deeper rock near the valley axis and possible volcanic rocks interlayered with the alluvial valley fill. Gravity survey data indicate the greatest depth to rock to be approximately 6200 feet (1890 m) below the surface in the area of generalized cross section A-A' (Figure 3.3-6). The basin is bounded on the east, west, and north by steep gradients in basement topography typical of those associated with normal faults. A fault scarp exposed along the east side of the valley coincides with one inferred basement fault with displacement down on the basinward side. A pediment surface, ranging in depth from zero to approximately 400 feet (122 m), is inferred along the valley margins, the basinward limits being located near the surface projection of the basement faults. Rock exposures and shallow (<150 feet; <46 m) rock are not known basinward of these pediment limits. The subsurface basin configuration is illustrated in Figures 3.3-4 and 3.3-6.

Ground-water depths within the basin are greater than 300 feet (92 m) and generally exceed 400 feet (122 m). This is based on information from five wells and regional ground-water resource evaluations.

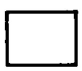
3.3.3 Engineering and Geophysical Properties

Engineering and geophysical properties of the predominant geologic units of Dry Lake Valley are summarized in Table 3.3-3



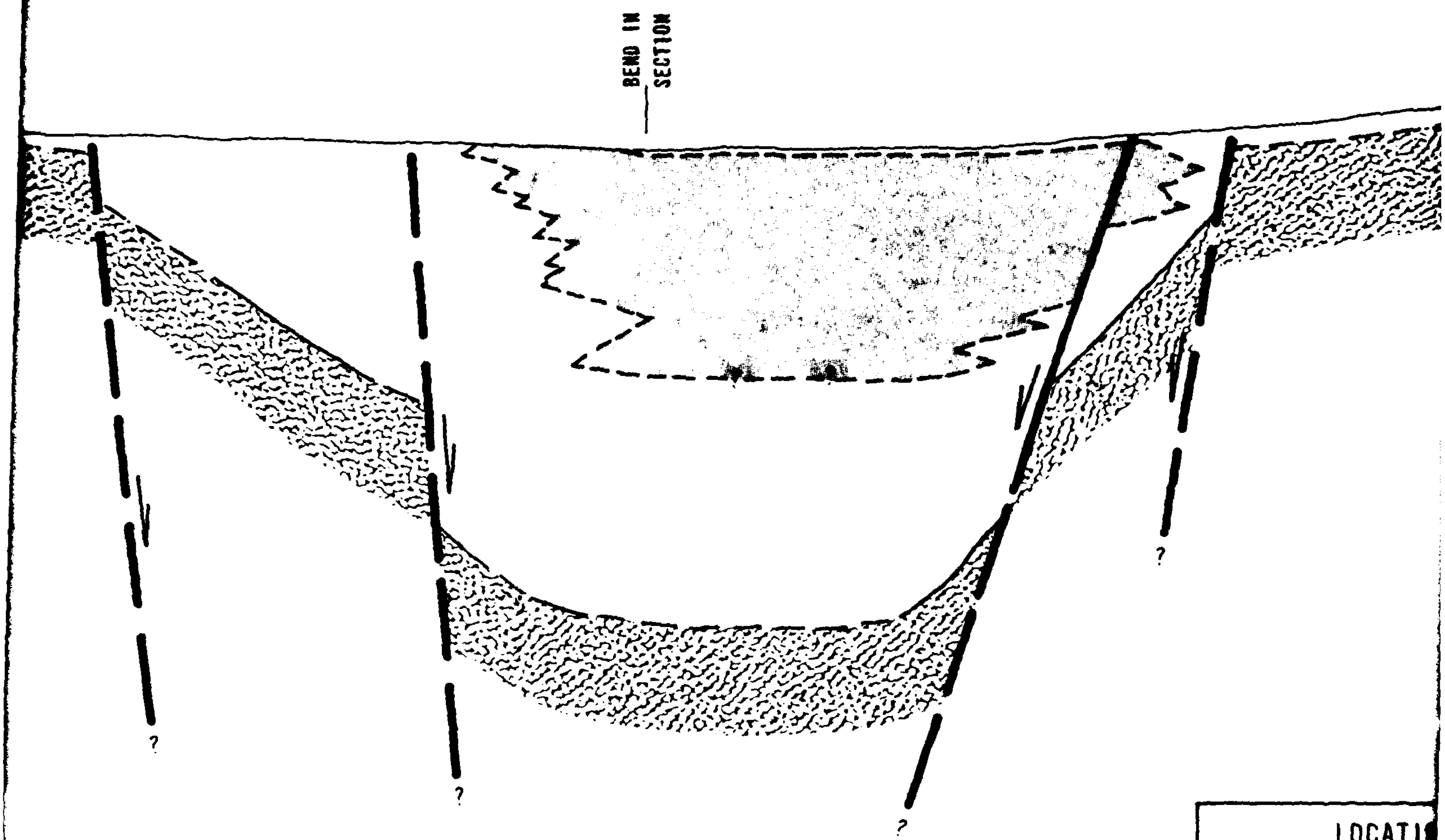
EXPLANATION

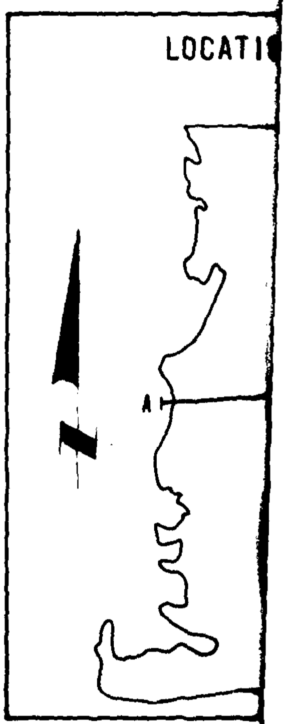
Playa and older lacustrine and or playa deposits



Undifferentiated basin-fill deposits;
Alluvial, fluvial, eolian, lacustrine, and playa deposits

Undifferentiated
Volcanic and sedimentary rocks



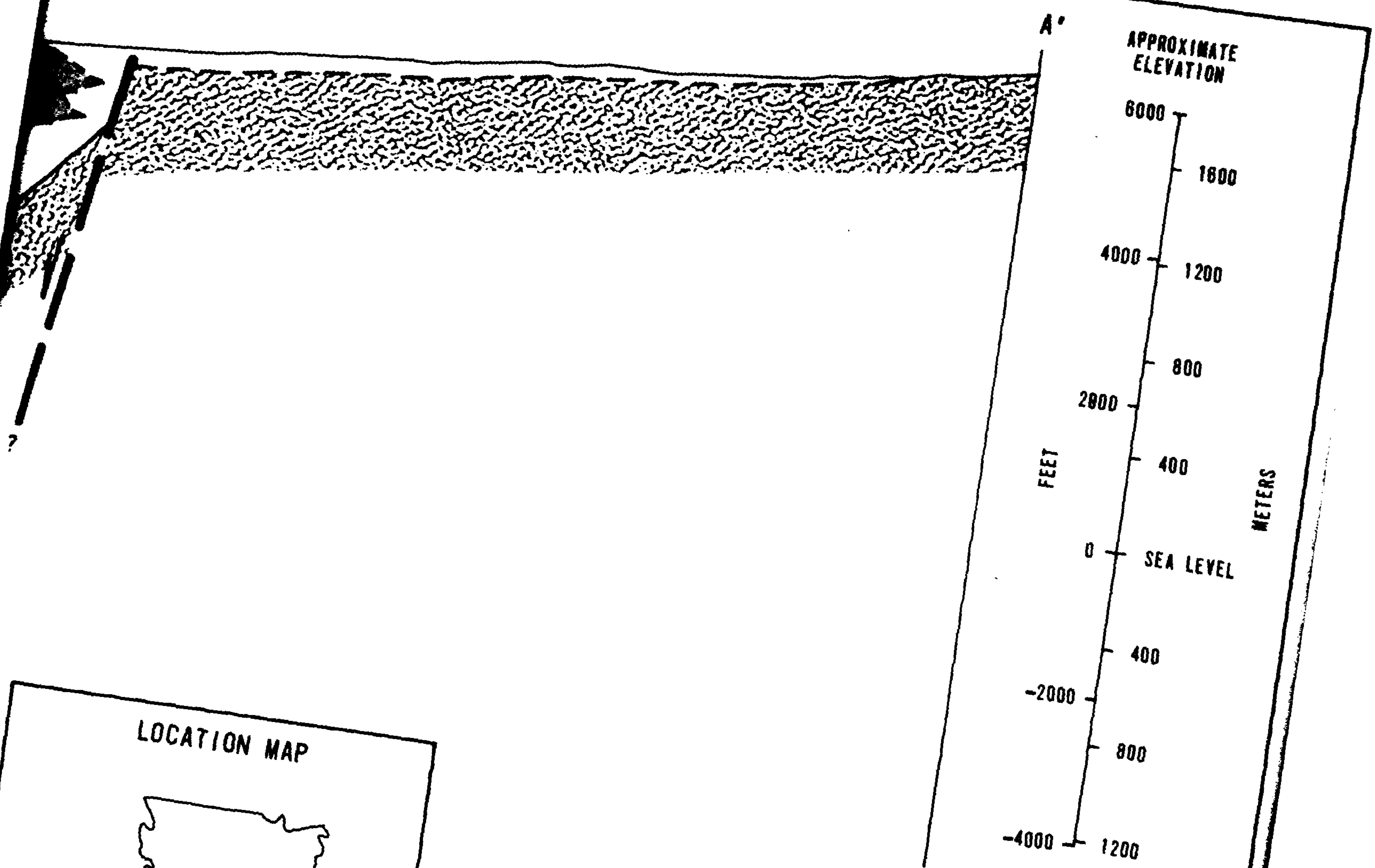


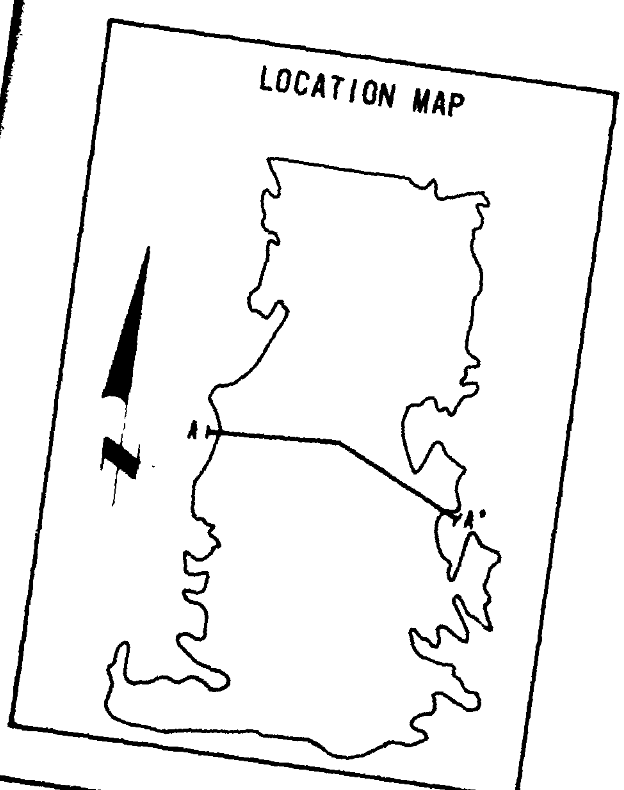
EXPLANATION

posits

Contacts - dashed where inferred

Faults - dashed where inferred





Horizontal Scale: 1" ≈ 1 Mile (1.6 km)
Vertical Scale: 1" = 2000' (610 m)
Vertical Exaggeration: 2.6x

GENERALIZED GEOLOGIC CROSS SECTION
DRY LAKE VALLEY, NEVADA
GREAT BASIN CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE 3.3-6

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ENGINEERING AND GEOPHYSICAL PROPERTIES	Intermediate and younger alluvial fan deposits (A5i and A5y)	Lacustrine and or playa d (A4 and A4o)
UNIFIED SOIL CLASSIFICATION SYMBOL(S)	SM, SW, SP, SC, GP, GM, GW	CH, MH, ML, SM
GENERAL PROPERTIES		
DRY DENSITY pcf(kg m^3)	79-120 (1265-1922)	70-94 (1121-1506)
MOISTURE CONTENT (%)	0.2-27.7	10-42
DEGREE OF SATURATION (%)	18-75	28-95
SPECIFIC GRAVITY	2.64-2.67	2.61±
DEGREE OF CEMENTATION	None to moderate	None to weak
COMPRESSIONAL WAVE VELOCITIES fps(mps)	1240-4870 (378-1484)	1000-4700 (305-143
ELECTRICAL CONDUCTIVITY (mhos m)	DNA	DNA
GRAIN SIZE DISTRIBUTION (%)		
BOULDERS >12 inches(30cm)	0-5	0
COBBLES 3 to 12 inches(8to 30cm)	0-12	0
GRAVEL	0-70	0
SAND	25-98	0-79
SILT AND CLAY	0-48	21-94
PLASTICITY DATA		
LIQUID LIMIT	21-23	27-108
PLASTICITY INDEX	NP-11	NP-60
COMPRESSIBILITY DATA		
COMPRESSION AT 4 ksf(192kN/m^2) (%)	1-5	1 0-2 6
SWELL OR COLLAPSE UPON SATURATION (%)	0.5-1.8 (Swell)	0.8-2.8(Swell)
SHEAR STRENGTH DATA		
UNCONFINED COMPRESSION ksf(kN m^2)	3 3-4.1 (158-196)	2 9-5 4 (139-259
CD TRIAXIAL COMPRESSION	c = 0-6 ksf (287 kN m^2), ϕ = 33°-40	c = 0-4 ksf (192 kN m^2),
DIRECT SHEAR ksf(kN m^2)	3.7-8.2 (177-393)	DNA
COMPACTION AND CBR DATA		
MAXIMUM DRY DENSITY pcf(kg m^3)	124.0-128.5 (1986-2058)	110.8±(1775±)
OPTIMUM MOISTURE CONTENT (%)	8.5-10.0	16.5±
CBR AT 90% RELATIVE COMPACTION	14-40	3±

DNA=DATA NOT AVAILABLE (INSUFFICIENT DATA OR TESTS NOT PERFORMED)

GEOLOGIC UNITS	
ne and or playa deposits (A4 and A4o)	
CH, MH, ML, SM	
70-94 (1121-1506)	
10-42	
28-95	
2.61±	
None to weak	
1000-4700 (305-1433)	
DNA	
0	
0	
0	
0-79	
21-94	
27-108	
NP-60	
1 0-2 6	
0.8-2.8(Swell)	
2 9-5 4 (139-259)	
4 ksf (192 kN m^2), ϕ =20 -32	
DNA	
110.8±(1775±)	
16.5±	
3±	

RANGE OF ENGINEERING AND GEOPHYSICAL PROPERTIES DRY LAKE VALLEY, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

TABLE 3.3-3

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and Figure 3.3-7. Younger and intermediate alluvial fan deposits are combined into one unit since they could not be differentiated at depth. Alluvial deposits consist predominantly of dense to very dense sands and sandy gravels which are slightly compressible and have moderately high shear strengths. Playa deposits are composed primarily of stiff to very stiff silts and clays, which are moderately compressible and have moderate shear strengths.

3.3.4 Conclusions

The following favorable and unfavorable geotechnical conditions for deployment of MX system at Dry Lake are based on the results of the Characterization study.

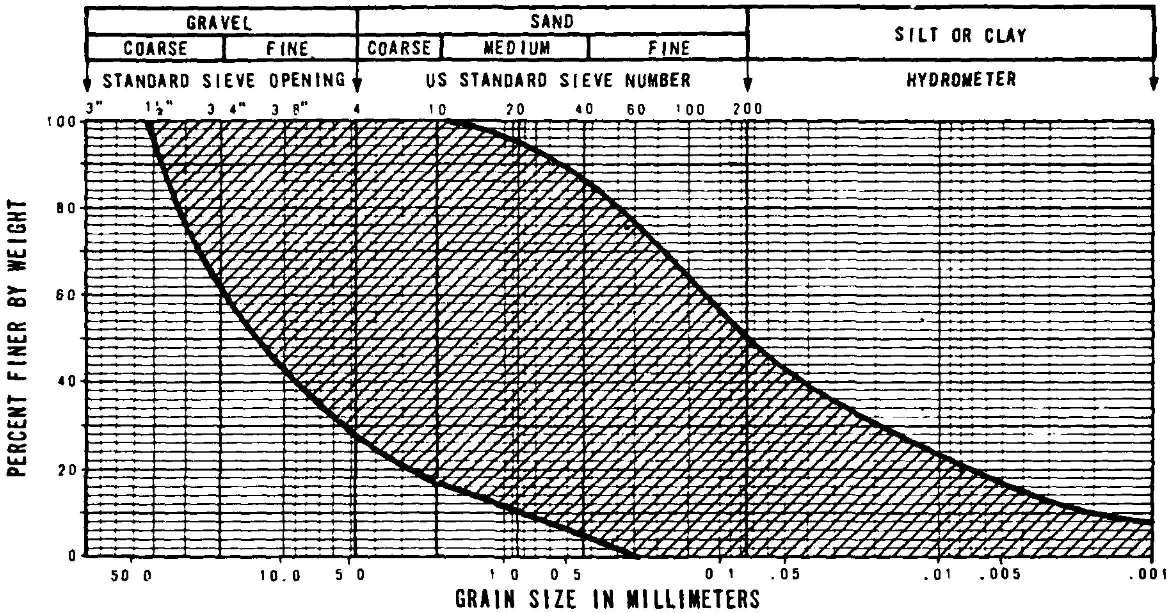
Favorable conditions:

- Surface slope is generally less than four percent requiring little preconstruction grading.

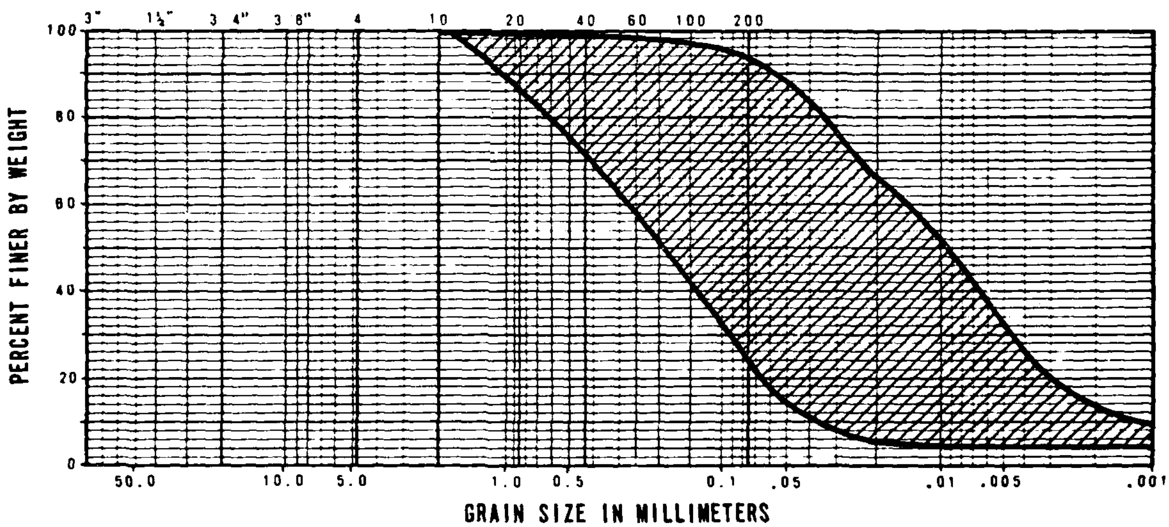
- Depths of drainages are typically less than 5 feet (1.5 m), reducing the need for major drainage structures.

- Most of the surficial soils have good support characteristics for use as road subgrade.

- Subsurface soils are suitable for excavation of vertical shelters using augers. They are also generally suited for excavation of continuous trenches by an MX trencher and conventional excavations required for horizontal shelters. Suitability of soils for backfilling and compaction in the trench excavations is good.



A5



A4

RANGE OF GRADATION OF GEOLOGIC UNITS
DRY LAKE VALLEY, NEVADA
GREAT BASIN CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.3-7

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- o Sufficient quantities of aggregate and water required for roads and concrete are available within and/or adjacent to the site area.

- o Depth to rock is expected to be greater than 150 feet (46 m) over 80 percent of the site.

- o Depth to ground water is greater than 300 feet (92 m) in all areas.

- o Land is administered by BLM.

Unfavorable conditons:

- o Few roads and facilities exist at the site requiring additional expense for construction of new roads and facilities.

- o Localized zones of uncemented cohesionless soils exist at the site and these will be unstable during excavation for vertical shelters and trenches, thus requiring additional expense.

In summary, the Dry Lake characterization site presents favorable geotechnical conditions for deployment of the present MX basing mode concepts.

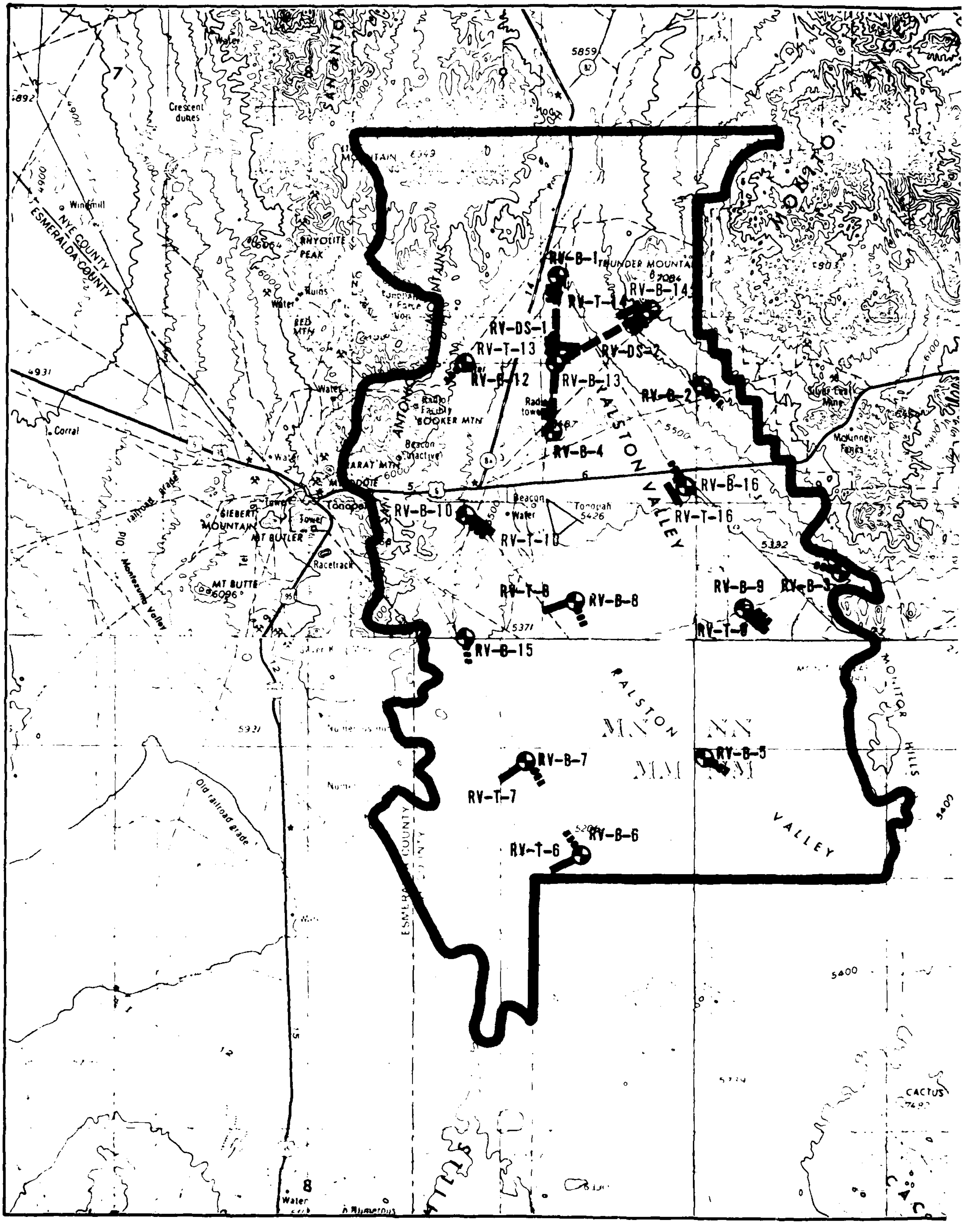
3.4 RALSTON VALLEY SITE: GREAT BASIN CSP

Ralston Valley lies in the western portion of the Great Basin CSP (Figures 3.3-1 and 3.3-2). Geotechnical data from this site are presented to provide additional information on siting conditions within the CSP. While there are many similarities between Dry Lake and Ralston Valleys, some notable differences are apparent, particularly regarding the extent and distribution of geologic units and depth to rock and water.

The Ralston Valley site covers an area of 182 nm^2 (624 km^2) in western Nye County Nevada. The site is bounded by mountain ranges on the east and west, Nellis Bombing and Gunnery Range on the south and is open to the northern part of Ralston Valley on the north. Field activities of the characterization study are identified in Figure 3.4-1. The scope of both the field and laboratory activities is presented in Table 3.4-1.

3.4.1 Surficial Geology and Terrain

Alluvial fan deposits of younger and intermediate age are the predominant surficial geologic units within the characterization site (Figure 3.4-2). The younger fan deposits cover approximately 23 percent of the area while the intermediate fan deposits cover 18 percent. Undifferentiated soil deposits cover 24 percent of the area. Playa deposits cover approximately three percent of the surface. Another ten percent of the area consists of smaller playas mapped as part of the playa and undifferentiated soil deposits. Playas located near the valley center and alluvial deposits located between the playas and the mountain fronts form an interfingering stratigraphic



RV-B-1
RV-T-14
RV-B-14
THUNDER MOUNTAIN
RV-DS-1
RV-T-13
RV-DS-2
RV-B-12
RV-B-13
RV-B-2
RV-B-4
RV-B-16
RV-T-16
RV-B-10
RV-T-10
RV-T-8
RV-B-8
RV-B-9
RV-B-3
RV-T-9
RV-B-15
RV-B-7
RV-T-7
RV-B-5
RV-T-6
RV-B-6
RALSTON VALLEY
NYE COUNTY
ESMERALDA COUNTY
Crescent dunes
Windmill
RHYOLITE PEAK
BOOKER MTN
Tonopah
SIEBERT MOUNTAIN
MT BUTLER
MT BUTTE
Racetrack
Old railroad grade
Montezuma Valley
Corral
Beacon
Tonopah 5426
MONITOR HILLS
CACTUS

AD-A114 214 FUGRO NATIONAL INC LONG BEACH CA F/G 8/6
MX SITING INVESTIGATION GEOTECHNICAL SITING STATUS REPORT. VOLU--ETC(U)
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UNCLASSIFIED FN-78-JUN-VOL-1 NL

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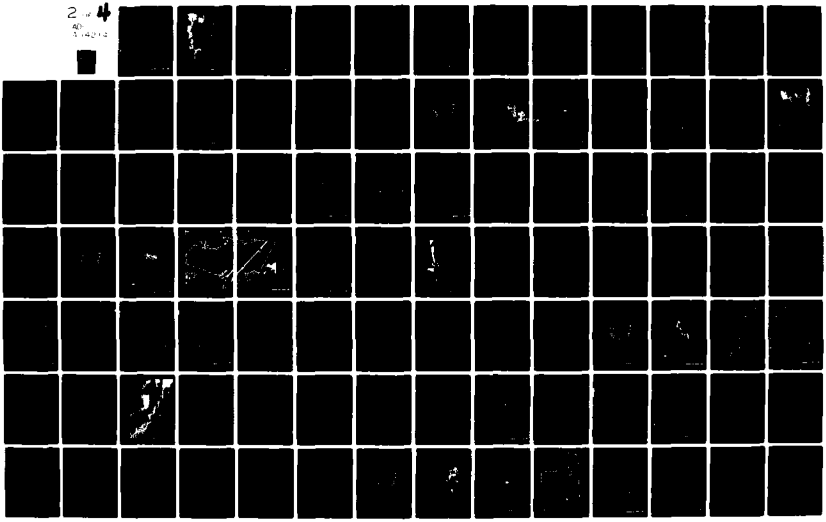
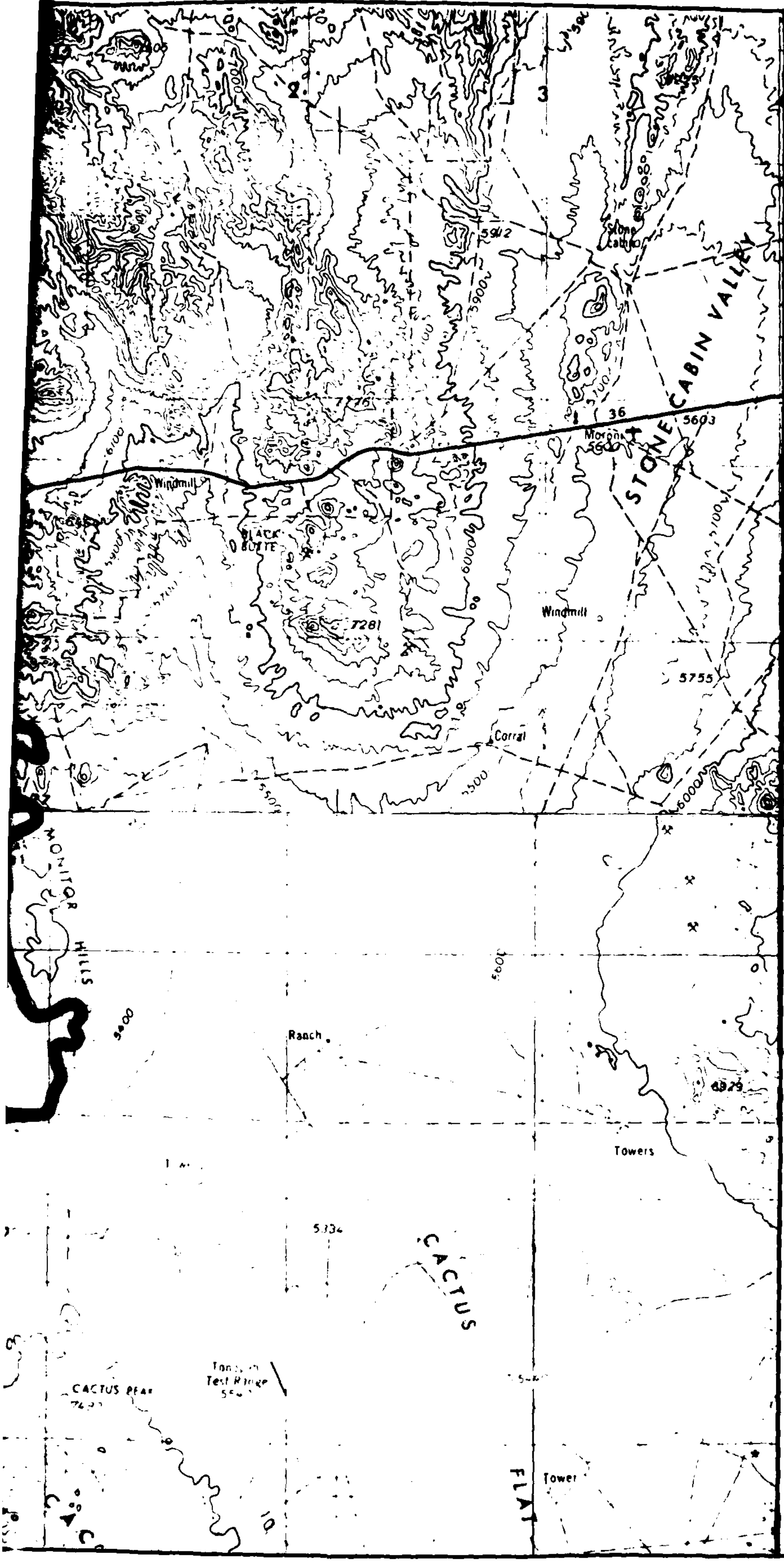
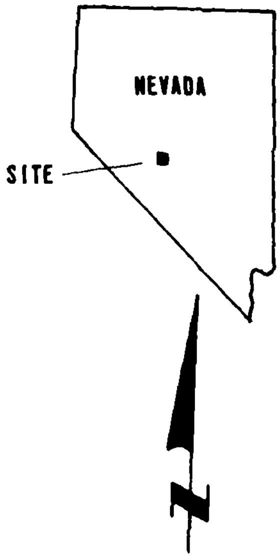




EXPLANATION

- Boring
- Deep Seismic refraction line
- Trench
- Seismic refraction line

SITE LOCATION



1:250,000
1" = 3.2 Nautical Miles
(APPROXIMATE)

ACTIVITY LOCATION MAP
RALSTON VALLEY, NEVADA
GREAT BASIN, CSP

MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE - SAMSO	FIGURE 3.4-1

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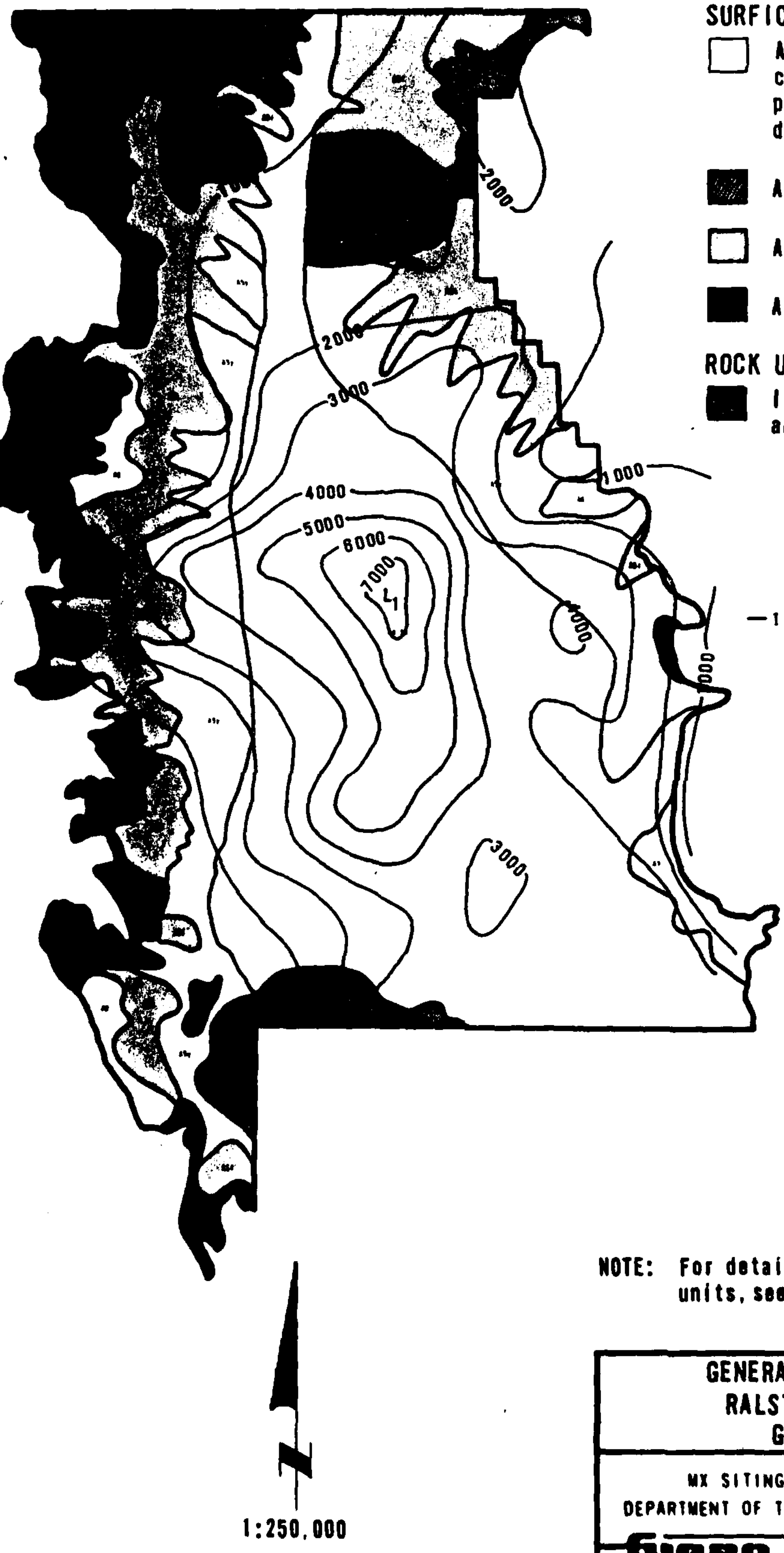

EXPLANATION

SURFICIAL GEOLOGIC UNITS

A1, A3, A5y, A6 and Au - stream channel, eolian, younger fan, pediment and undifferentiated deposits

A4 - playa deposits

A5i - intermediate fan deposits

A5o - older fan deposits

ROCK UNITS

I1 and I2 - Igneous; intrusive and extrusive

SYMBOLS

—1000— Estimated depth to bedrock, contour interval = 1000 feet.

L_1. Gravity low - inferred caldera

NOTE: Basement depths and configuration based on gravity interpretation

NOTE: For detailed description of geologic units, see Table 3.4-2 and Appendix.

GENERALIZED GEOLOGIC MAP
RALSTON VALLEY, NEVADA
GREAT BASIN CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.4-2

FUGRO NATIONAL, INC.

GEOLOGY AND GEOPHYSICS

TYPE OF ACTIVITY	NUMBER OF ACTIVITIES
Geological mapping stations	27
Shallow refraction	15
Deep refraction	2
Downhole velocity	3
Gravity survey	577

ENGINEERING

NUMBER OF BORINGS	DEPTH FEET(METERS)
2	30 (9)
9	75-100 (23-30)
4	300 (91)
NUMBER OF TRENCHES	DEPTH FEET(METERS)
8	16 (5)

ENGINEERING-LABORATORY TESTS

TYPE OF TEST	NUMBER OF TESTS
Moisture/density	188
Specific gravity	15
Sieve analysis	144
Hydrometer	63
Atterberg limits	32
Consolidation	10

TYPE OF TEST	NUMBER OF TESTS
Unconfined compression	12
Triaxial Compression	21
Direct shear	16
Compaction	7
CBR	3
Chemical analysis	8

SCOPE OF FIELD AND LABORATORY ACTIVITIES
RALSTON VALLEY, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE 3.4-1

FUGRO NATIONAL, INC.

sequence. Alluvial fan deposits are typically silty sands with gravel, ranging from sandy gravels near the mountain front to sandy silts near the playas. Playa deposits are generally silts. These three units along with the remaining surficial units are described in Table 3.4-2.

Surface slopes and depths of drainage incision vary with geologic units, both generally increasing with relative age of the alluvial fan deposits (Table 3.4-2). Maximum surface slope (excluding older alluvial fan deposits) is ten percent with typical slopes of three percent. Maximum depths of incision (excluding older alluvial fan deposits) are 15 feet (5 m) with typical depth of five feet (1.5 m).

3.4.2 Subsurface Conditions

The composition of the soils with depth is illustrated by the soil profile shown in Figure 3.4-3. The gradation of these soils is similar to the surficial geologic units; however, the profile indicates that coarse and fine-grained soils are interbedded.

Geophysical investigations indicate shallower bedrock near the mountain fronts, deeper bedrock near the valley axis, and volcanic rocks possibly interlayered with the alluvial valley fill. Gravity survey data indicate the greatest depth to bedrock is approximately 7400 feet (2257 m) below the surface in the area of L1 (Figure 3.4-2) along the generalized cross section A-A' (Figure 3.4-4). The basin is bounded on the

ENGINEERING GEOLOGY UNIT (f)	GEOLOGIC AGE	THICKNESS FEET (METERS)	DESCRIPTIVE NAME(S)	USCS SYMBOL(S)	AREAL EXTENT (SITE)	
					nm^2 (km^2)	PERCENT
Undifferentiated Non-Rock Deposits (Au)	Quaternary-Tertiary	Unknown	Silty Sand with Gravel	SM	45 (154)	24
Alluvial Outwash Deposits (Alw)	Quaternary	Unknown	Silty Sand, Sand	SM, SP	7 (24)	4
Lake Terrace Deposits (A2l)	Quaternary-Tertiary	Unknown	Silty Sand with Gravel	SM	1 (3)	<1
Eolian Deposits, Undifferentiated (A3)	Quaternary	0-20 (0-6)	Sand with Gravel	SP	3 (10)	2
Playa Deposits (A4)	Holocene	Unknown	Silt with Sand and Clay	ML	44 (151)	24
Younger Alluvial Fan Deposits (A5y)	Holocene	Unknown	Silty Sand with Gravel	SM	41 (141)	23
Intermediate Alluvial Fan Deposits (A5i)	Pleistocene	Unknown	Gravelly Silty Sand, Sand	SM, SW, SP	36 (123)	20
Older Alluvial Fan Deposits (A5o)	Pleistocene	Unknown	Gravelly Silty Sand	SM	5 (17)	3

NOTES:

(a) Mixed A1, A4, and A5 deposits.
(b) Consists of mixed A1, A5y and A5i deposits.
(c) Locally includes gravel, cobbles and boulders derived from upslope rock.
(d) Includes 21 percent mixed A4 and Au deposits; designated A4 Au on Figure 3.4-2.
(e) Includes two percent of area underlain by shallow rock, designated A6 on Figure 3.4-2.
(f) For generic description of geologic units, see Appendix.

[illegible]EAL EXTENT (SITE)		PROPERTIES OF SURFACE MATERIALS					SURFACE MORPHOLOGY		NOTES
[illegible]^2 (km^2)	PERCENT	GRADATION	CEMENTATION	MAXIMUM GRAIN SIZE	PAVEMENT/ PATINA	STAGE OF CALICHE	SLOPE (PERCENT)	DRAINAGE DEPTHS FEET(METERS)	
[illegible]5 (154)	24	Poor-Well	None-Moderate	Cobbles	None-Well/ None-Well	None-III	<1-10	0-25 (0-8)	(a)
7 (24)	4	Poor-Moderately well	Weak-Moderate	Boulders	None-Fair/ None-Fair	None-II	0-5	0-10 (0-3)	(b)
1 (3)	<1	Moderately well	Weak	Gravel	None-Fair/ None-Fair	None-I	1-5	0-2 (0-0.6)	
3 (10)	2	Poor	None-Weak	Cobbles	None/ None	None-I	0-10	0-5 (0-1.5)	(c)
44 (151)	24	Poor	None-Weak	Sand	None/ None	None-I	< 1	0-2 (0-0.6)	(d)
41 (141)	23	Poor-Well	None-Weak	Cobbles	None-Poor/ None-Poor	None-I	0-5	0-3 (0-1)	
36 (123)	20	Poor-Well	Weak-Moderate	Boulders	Poor-Well/ None-Fair	II	1-10	2-15 (0.6-5)	(e)
5 (17)	3	Moderately well-Well	Moderate-Strong	Boulders	Poor-Well/ Poor-Well	III	5-10	5-25 (1.5-8)	

DESCRIPTION OF SURFICIAL GEOLOGIC UNITS
RALSTON VALLEY, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

TABLE 3.4-2

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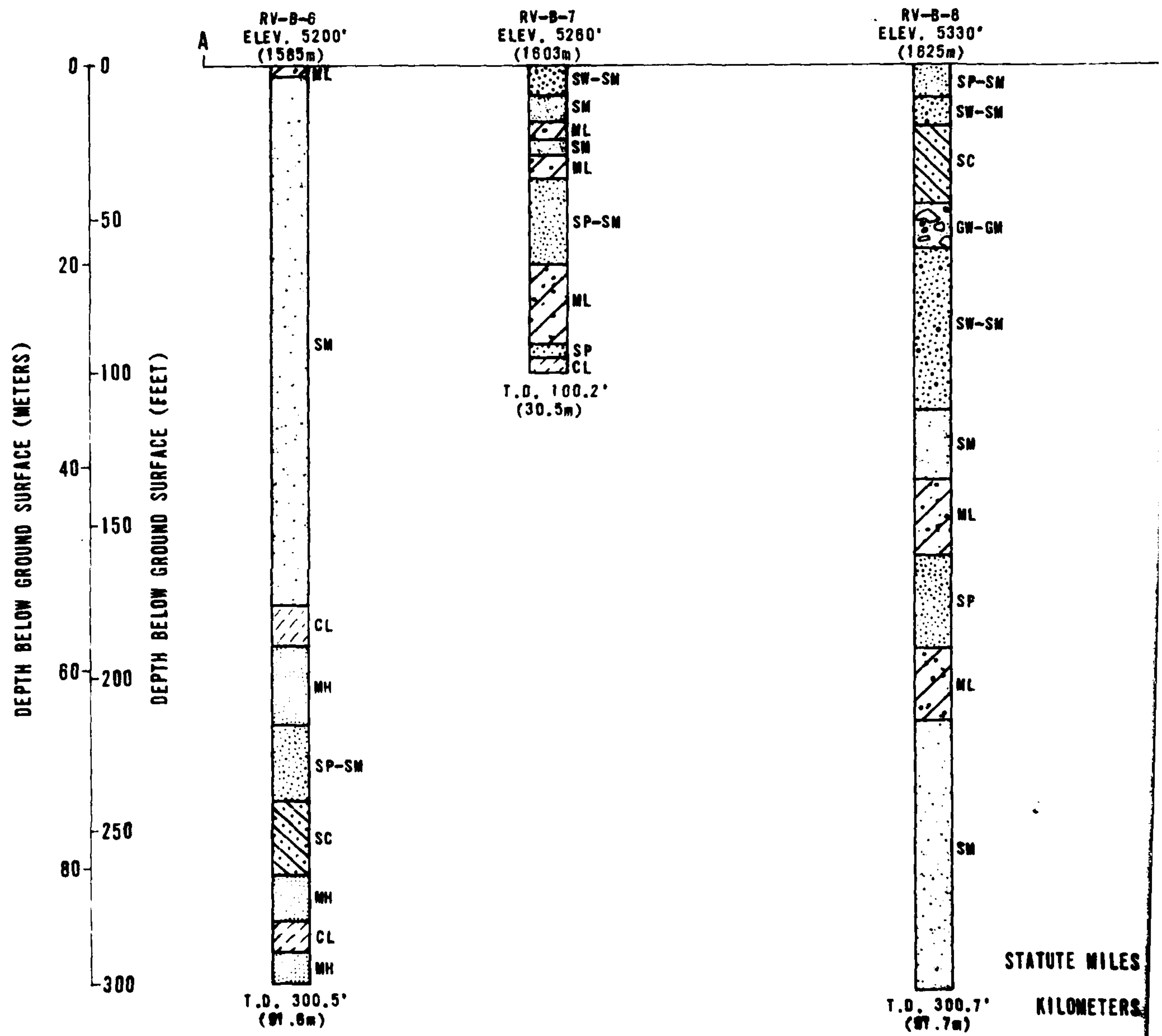
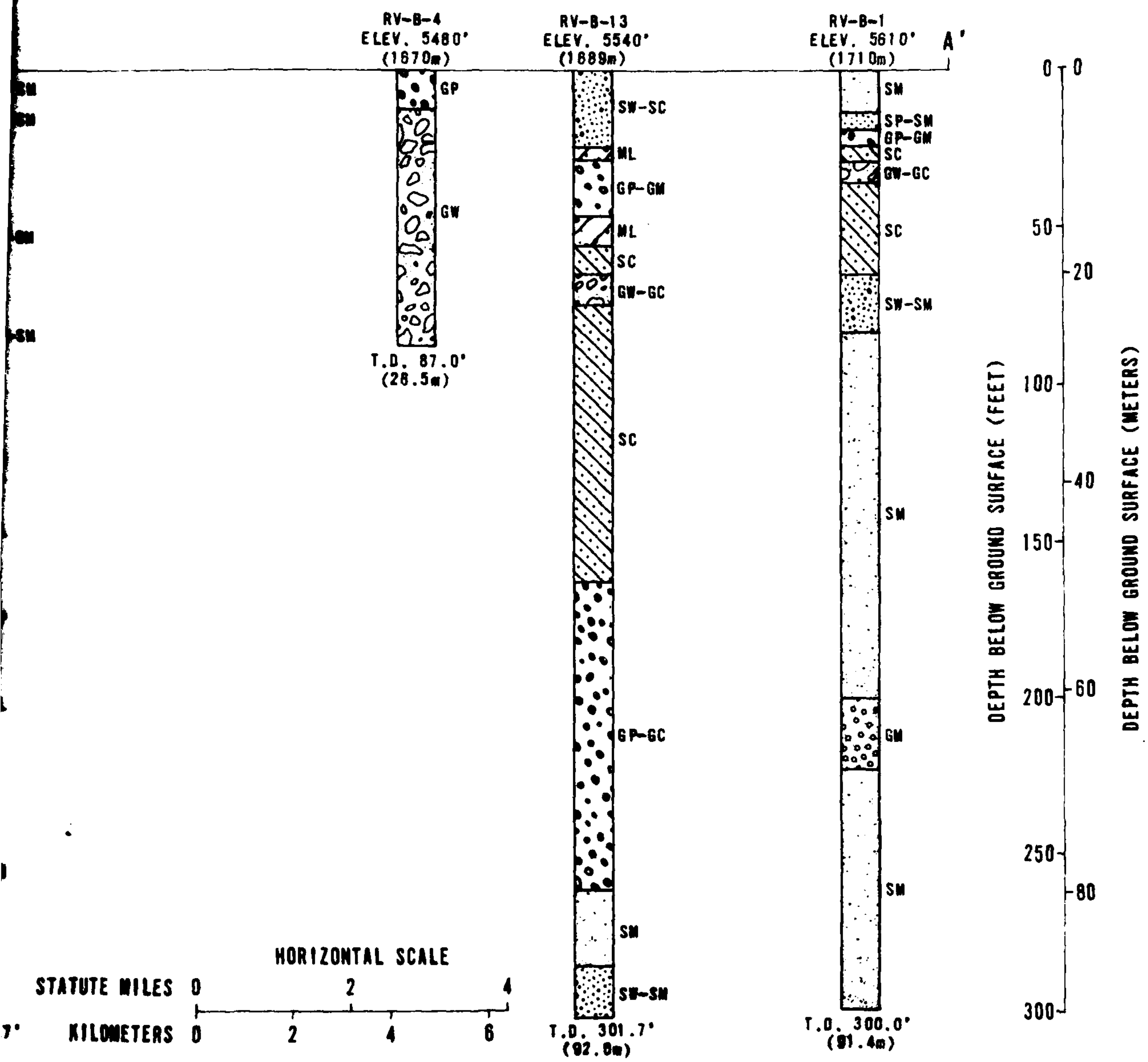
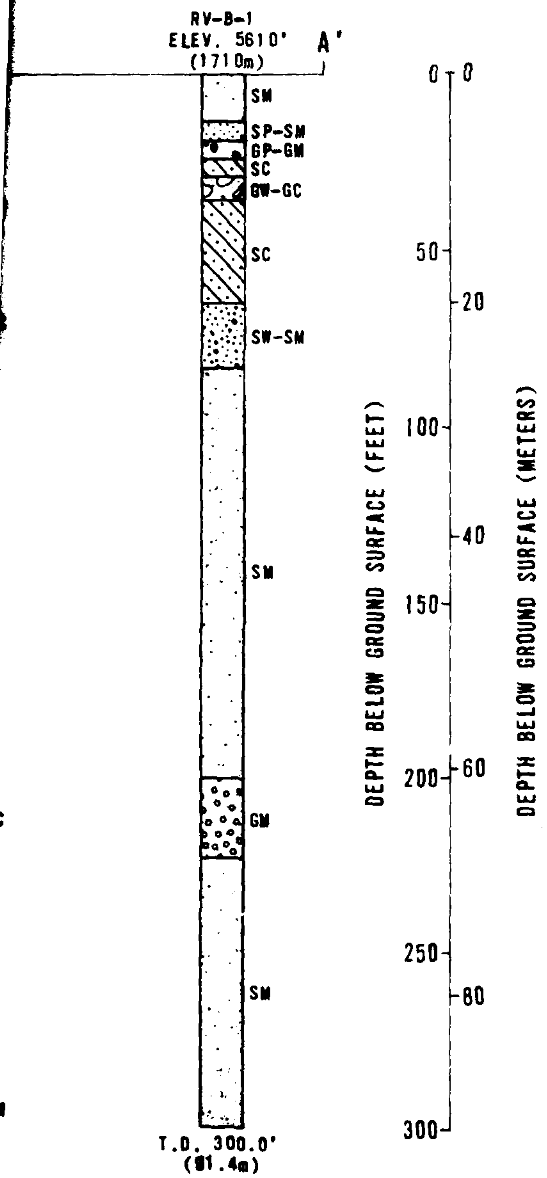
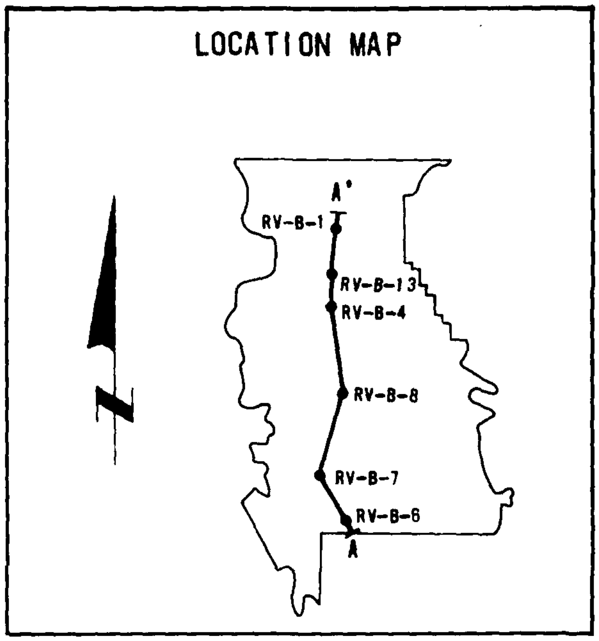


NOTES:
1. Ground surface elevations shown at locations of borings are approximate
2. T.D.= Total Depth
3. Soil types shown adjacent to soil column are based on Unified Soil Classification System (USCS) and are explained in the appendix



ification System



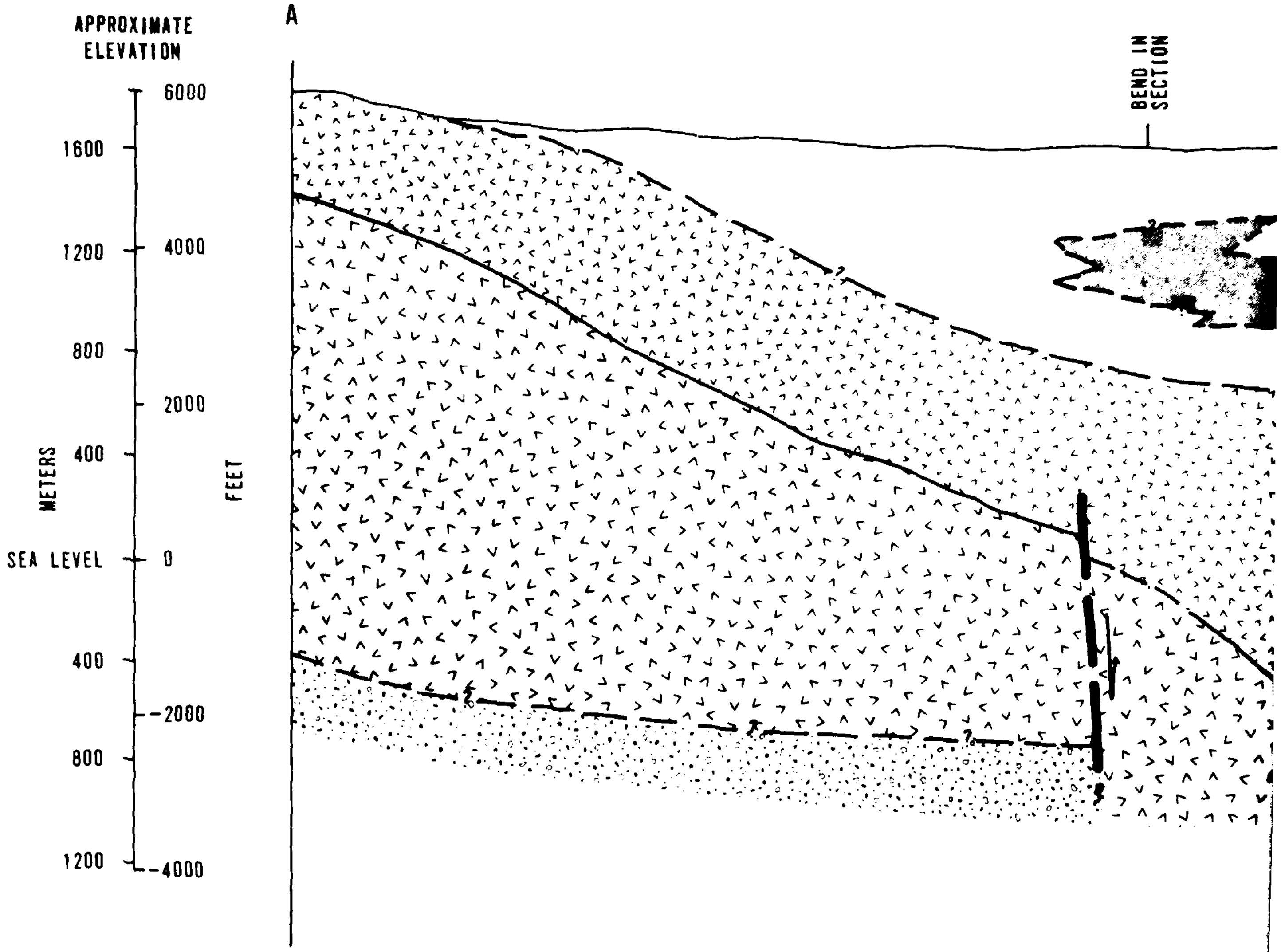


SOIL PROFILE
RALSTON VALLEY, NEVADA
GREAT BASIN CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.4-3

FUGRO NATIONAL, INC.



EXPLANATION

Undifferentiated basin-fill deposits;
alluvial, fluvial, eolian, lacustrine, and playa deposits

Older lacustrine and or playa deposits

Younger volcanic rocks
Volcanic flows and volcanoclastic rocks; predominantly late Tertiary

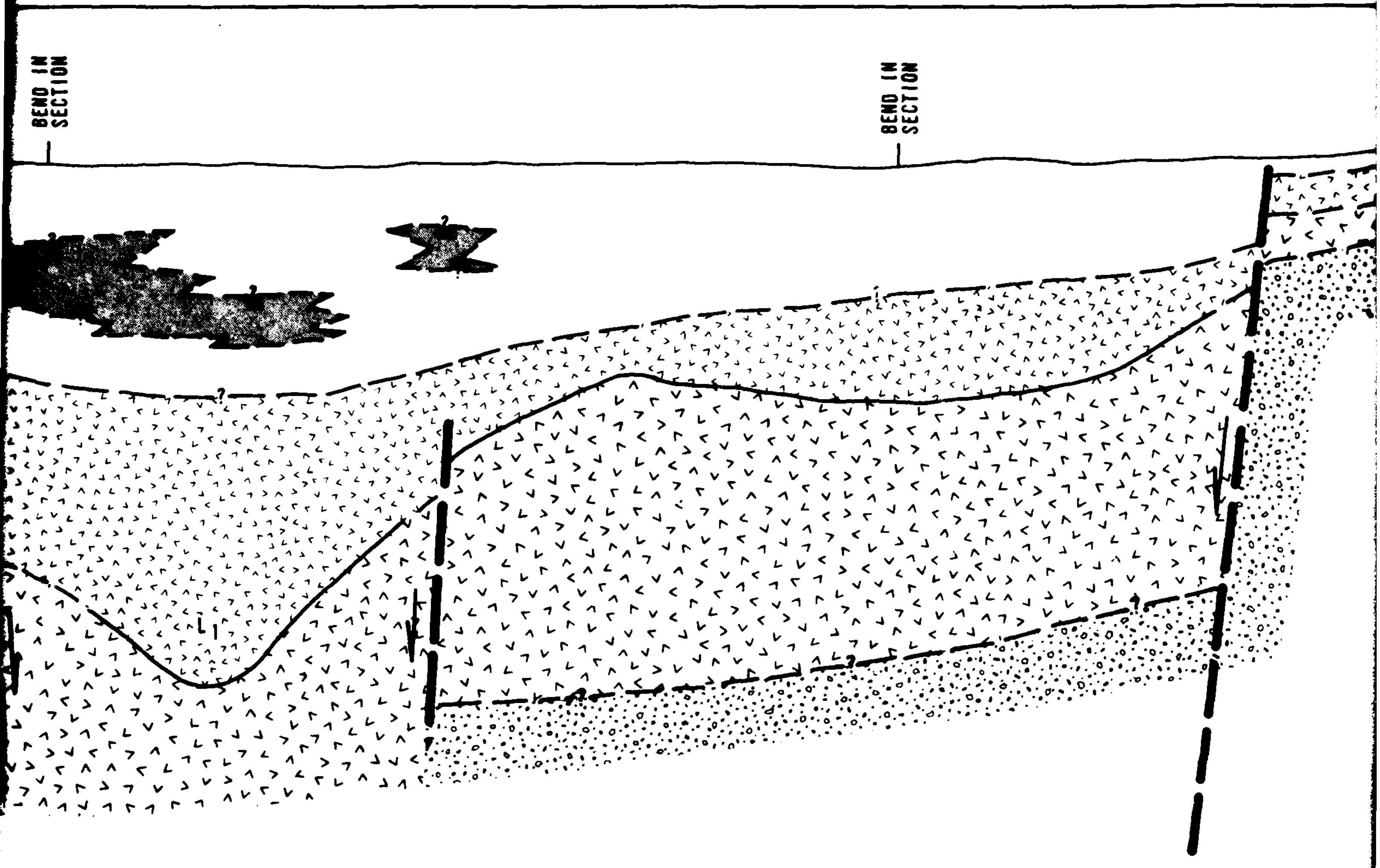
Older volcanic rocks
Volcanic flows (?) and volcanoclastic (?) rocks; predominantly early Tertiary (?) and Cretaceous (?)

Pal

Con

Fau

L_1 Gr

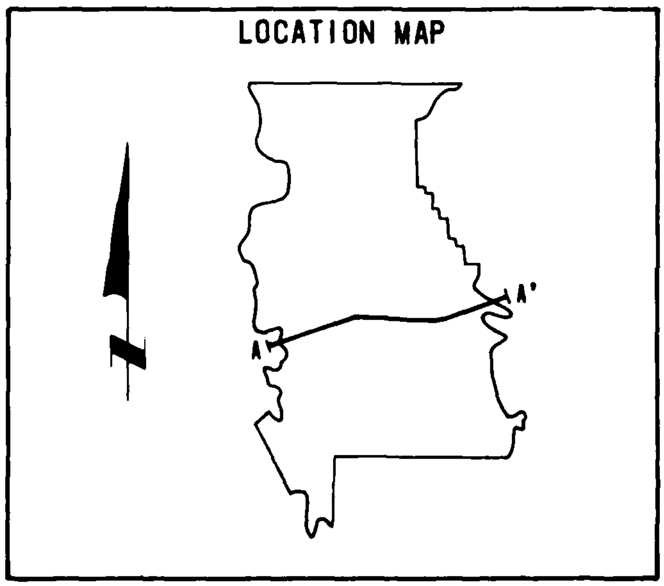


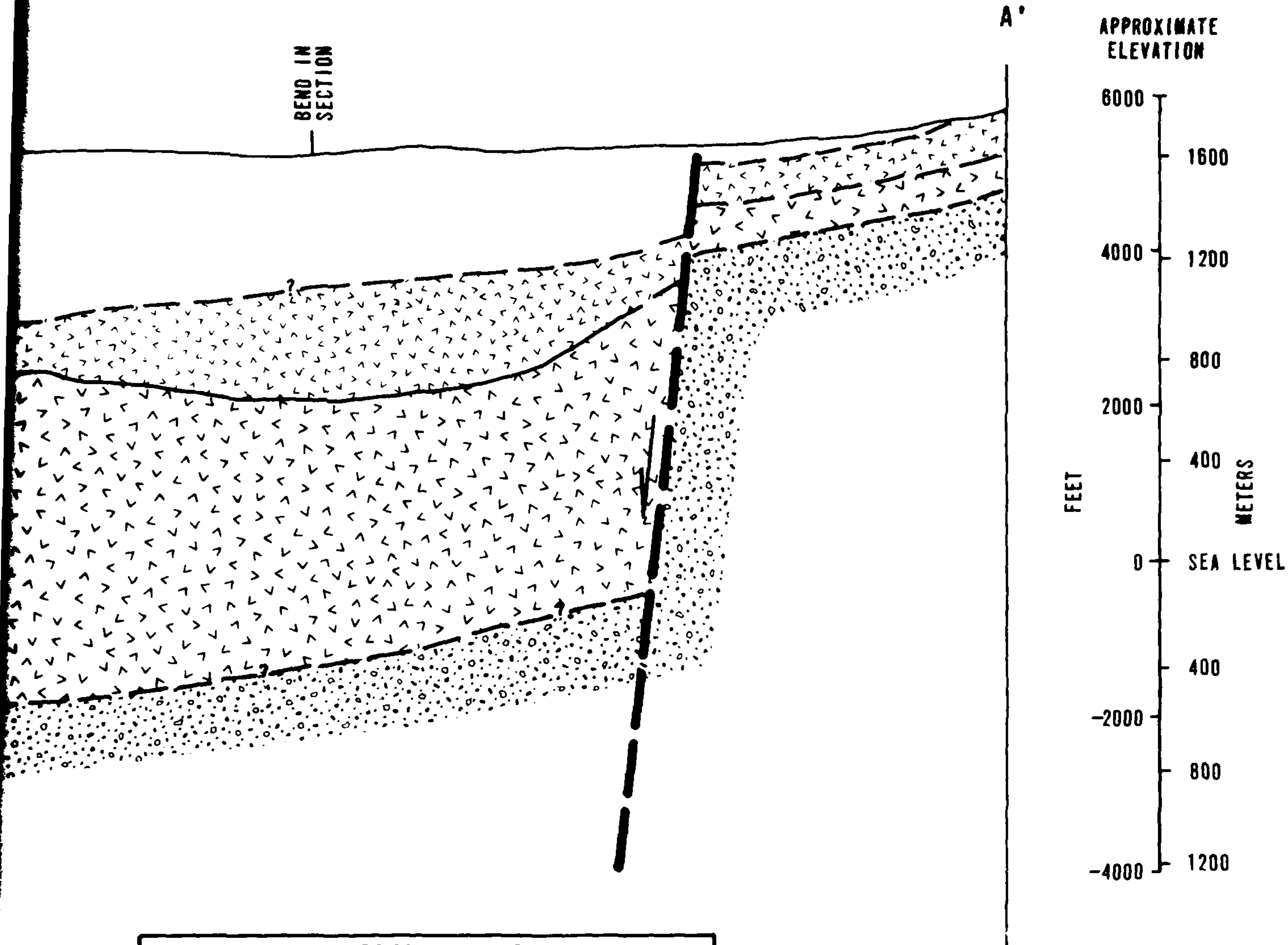
Paleozoic rocks
Sedimentary rocks; predominantly limestone and dolomite with minor clastic beds

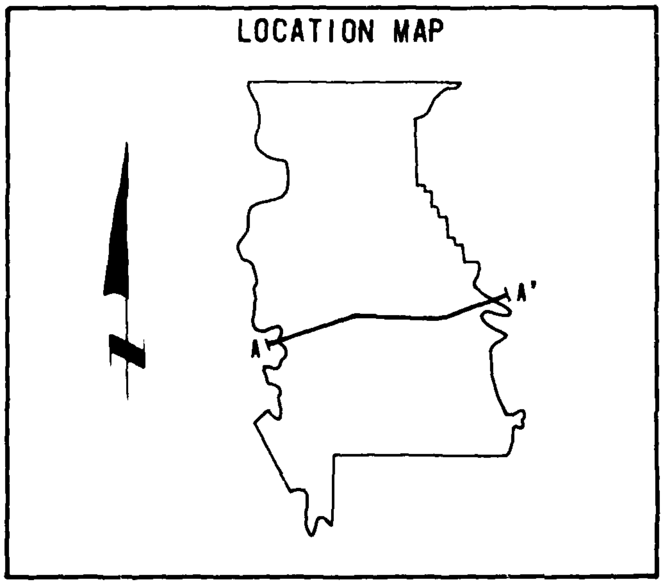
Contacts - dashed where inferred

Faults - dashed where inferred

L_1 Gravity low - inferred caldera







Horizontal Scale: 1" ≈ 1 Mile (1.6 km)
Vertical Scale: 1" = 2000' (610 m)
Vertical Exaggeration: 2.6x

GENERALIZED GEOLOGIC CROSS SECTION
RALSTON VALLEY, NEVADA
GREAT BASIN CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.4-4

FUGRO NATIONAL, INC.

east by steep gradients in basement topography typical of those associated with normal faults. No basement rocks are present at the surface west of this fault and a pediment is inferred east of the fault. The basin center is interpreted as a collapsed caldera overlain by younger volcanic rocks and basin-fill deposits (Figure 3.4-4). The subsurface basin configuration is illustrated in Figures 3.4-2 and 3.4-4.

Ground-water depths within the basin are generally greater than 200 feet (61 m) except for an area north of Thunder Mountain (Tonopah domestic water supply) where ground-water levels range from 10 to 100 feet (3 to 30 m). The ground-water contact between these areas is an east-west contact which does not show on the gravity contour map and is therefore assumed to represent stratigraphic changes across the contact. Data in Ralston Valley south of the Tonopah well field are based on information from four wells and regional ground-water information.

3.4.3 Engineering and Geophysical Properties

Engineering and geophysical properties of the predominant geologic units are summarized in Table 3.4-3 and Figure 3.4-5. Younger and intermediate alluvial fan deposits are combined into one engineering unit since they could not be differentiated at depth. Alluvial deposits consist primarily of dense to very dense sands and sandy gravels which are slightly compressible and have moderately high shear strengths. The playa deposits predominantly consist of stiff to very stiff silts and clays which are moderately compressible and have moderate shear strength.

ENGINEERING AND GEOPHYSICAL PROPERTIES	Intermediate and younger alluvial fan deposits (A5i and A5y)	Lacustrine and/or [illegible] (A4 and [illegible]
UNIFIED SOIL CLASSIFICATION SYMBOL(S)	SW. SP. SM. GP. GM	ML. CL. MH. [illegible]
GENERAL PROPERTIES		
DRY DENSITY pcf(kg m^3)	86–118 (1378–1890)	75–107 (120[illegible]
MOISTURE CONTENT (%)	1–22	6–40
DEGREE OF SATURATION (%)	42–74	21–90
SPECIFIC GRAVITY	2 54–2 60	2.56–2.[illegible]
DEGREE OF CEMENTATION	Uncemented to moderate	Uncemented t[illegible]
COMPRESSIONAL WAVE VELOCITIES fps(mps)	1000–6900 (305–2103)	1340–5700 (4[illegible]
ELECTRICAL CONDUCTIVITY (mhos m)	DNA	DNA
GRAIN SIZE DISTRIBUTION (%)		
BOULDERS >12 inches(30cm)	0–1	0
COBBLES 3 to 12 inches(8to 30cm)	0–8	0
GRAVEL	0–61	0
SAND	25–86	13–88
SILT AND CLAY	5–33	12–87
PLASTICITY DATA		
LIQUID LIMIT	NP	36–66
PLASTICITY INDEX	NP	NP–30
COMPRESSIBILITY DATA		
COMPRESSION AT 4 ksf/192kN/m^2) (%)	DNA	1 4–2 [illegible]
SWELL OR COLLAPSE UPON SATURATION (%)	DNA	1 4–2 7 [illegible]
SHEAR STRENGTH DATA		
UNCONFINED COMPRESSION ksf(kN m^2)	DNA	2 4–4.3 ([illegible]
CD TRIAXIAL COMPRESSION	c=0-8 ksf (383 kN m^2), ϕ=33-39°	c=0-4 ksf (192 [illegible]
DIRECT SHEAR ksf(kN m^2)	2 7–10.8 (129–517)	1 2–5.2 ([illegible]
COMPACTION AND CBR DATA		
MAXIMUM DRY DENSITY pcf(kg m^3)	118–122 (1890–1954)	DNA
OPTIMUM MOISTURE CONTENT (%)	9.8–11.5	DNA
CBR AT 90% RELATIVE COMPACTION	30–40	DNA

DNA = DATA NOT AVAILABLE (INSUFFICIENT DATA OR TESTS NOT PERFORMED)

GEOLOGIC UNITS	
trine and/or playa deposits (A4 and A4o)	
ML, CL, MH, SP, SM	
75-107 (1201-1714)	
6-40	
21-90	
2.56-2.59	
Uncemented to weak	
1340-5700 (408-1737)	
DNA	
0	
0	
0	
13-88	
12-87	
36-66	
NP-30	
1 4-2 2	
1 4-2 7 (Swell)	
2.4-4.3 (155-206)	
0-4 ksf (192 kN m^2), φ = 20-34°	
1 2-5.2 (57-249)	
DNA	
DNA	
DNA	

RANGE OF ENGINEERING AND GEOPHYSICAL PROPERTIES RALSTON VALLEY, NEVADA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

TABLE 3.4-3

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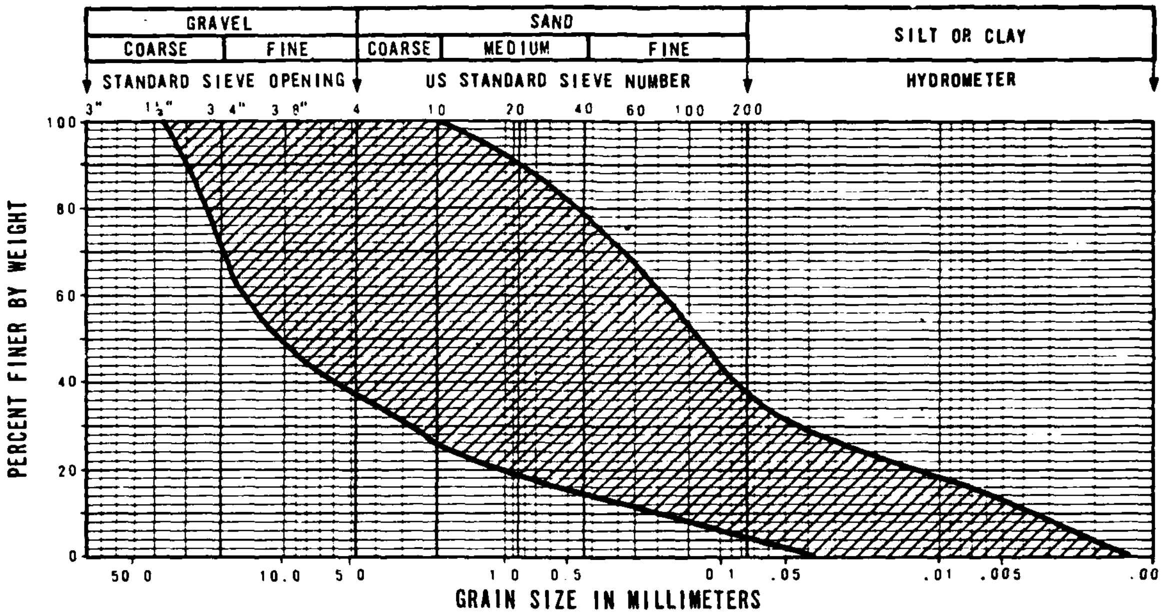
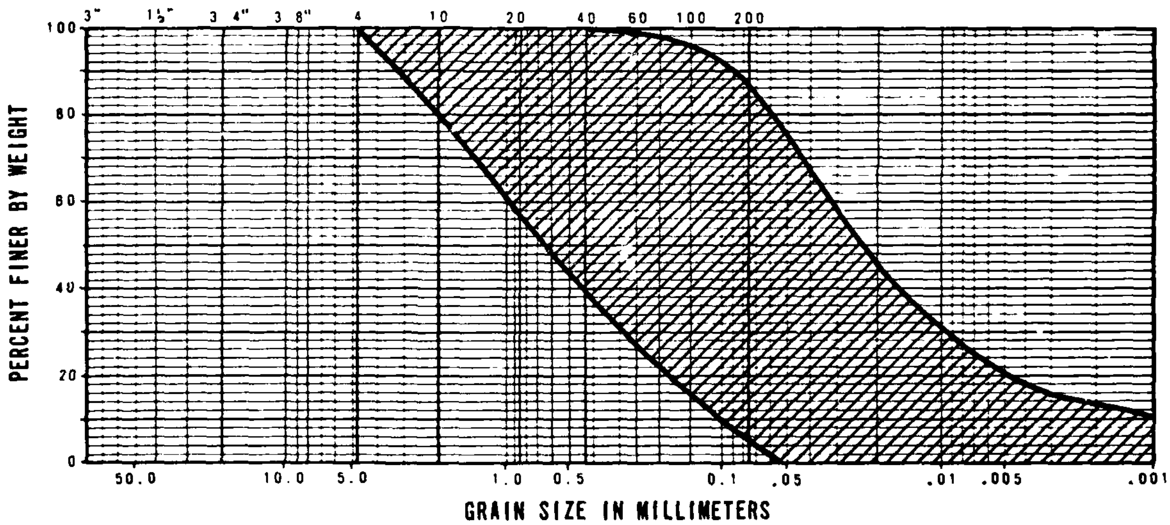


A5



A4

RANGE OF GRADATION OF GEOLOGIC UNITS
RALSTON VALLEY, NEVADA
GREAT BASIN CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.4-5

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3.4.4 Conclusions

The following favorable and unfavorable geotechnical conditions for deployment of the MX system at the Ralston site are based on the results of the Characterization study.

Favorable conditions:

- Surface slope is generally less than three percent requiring little preconstruction grading.
- Drainages are typically less than five feet (1.5 m) deep minimizing the need for major drainage structures.
- Most of the surficial soils have good support characteristics for use as road subgrade.
- Soils are suitable for excavation of vertical shelters using augers, continuous excavations by an MX trencher, and conventional excavations for horizontal shelters. Suitability of soils for backfilling and compaction in the trench excavations is good.
- Sufficient quantities of aggregate and water required for roads and concrete are available within and/or adjacent to the site area.
- Depth to rock is expected to be greater than 150 feet (46 m) over 80 percent of the area.
- Depth to ground water is greater than 200 feet (61 m) in about 95 percent of the area.
- Land is administered by BLM.

Unfavorable conditions:

- o Few roads exist within the site requiring additional expense for construction of new roads.
- o Borings and trenches indicate some localized zones of uncemented cohesionless soils which will be unstable during excavation for vertical shelters and trenches, thus requiring additional expense.
- o In the northern portion of the site (approximately five percent of site area) ground water is encountered at a depth of ten feet (3 m) requiring additional expense for excavation of vertical shelters. This area will be excluded for the trench basing mode.

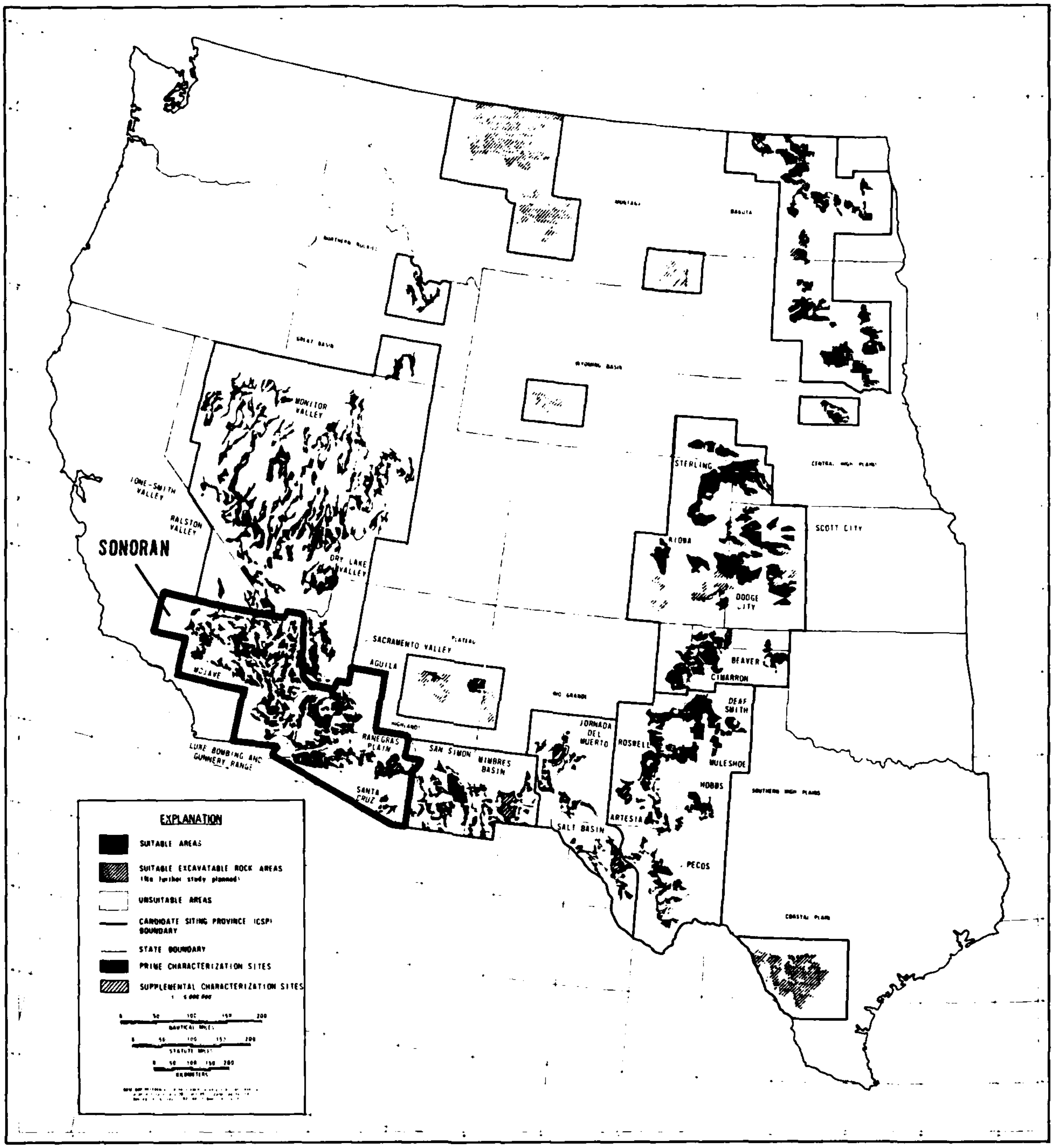
In summary, the geotechnical conditions at Ralston are similar to Dry Lake and are favorable for deployment of the present MX basing mode concepts.

3.5 LECHUGUILLA DESERT SITE: SONORAN CSP

The Sonoran CSP lies principally within the Sonoran Desert Section of the Basin and Range physiographic province and covers portions of southern Arizona, California and Nevada (Figure 3.5-1). The majority of suitable area is federally administered (BLM, 53%; DoD, 17%). Department of Defense land is apportioned among seven reservations (Luke Bombing and Gunnery Range, Yuma Proving Grounds, Edwards AFB, Fort Irwin, U. S. Naval Weapons Center, Chocolate Mountains AGR, and 29 Palms MCB). Thirteen percent is state owned land and 17 percent private or patented land. More than 95 percent of the land is being used as rangeland and the remainder for irrigation farming.

The CSP is characterized by predominantly north to northwest trending mountain ranges separated by fault controlled inter-montane basins that have a variety of engineering and geologic conditions. Five sites were selected to characterize geotechnical conditions within the CSP (Figure 3.5-2) based upon a review of regional geologic and engineering literature. Results of the Lechuguilla Desert investigation provide a sampling of geotechnical conditions encountered throughout the Sonoran CSP, particularly in southern Arizona.

The Lechuguilla Desert site covers an area of 166 nm^2 (569 km^2) situated in the Luke Bombing and Gunnery Range, Yuma County, Arizona (Figure 3.5-2). The site occupies a broad alluvial basin between the Copper Mountains and Baker Peaks to the east



LOCATION OF SONORAN CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.5-1

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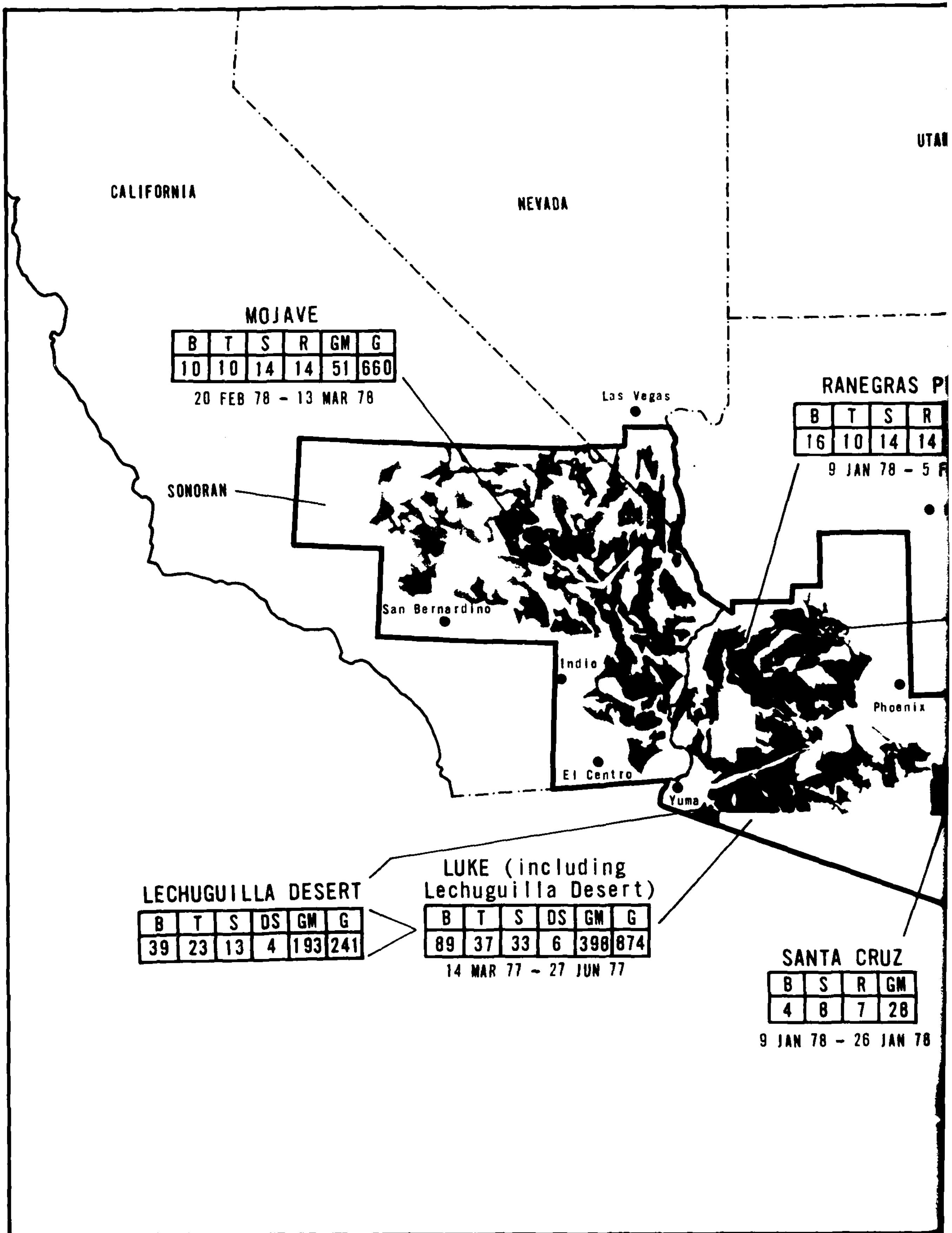
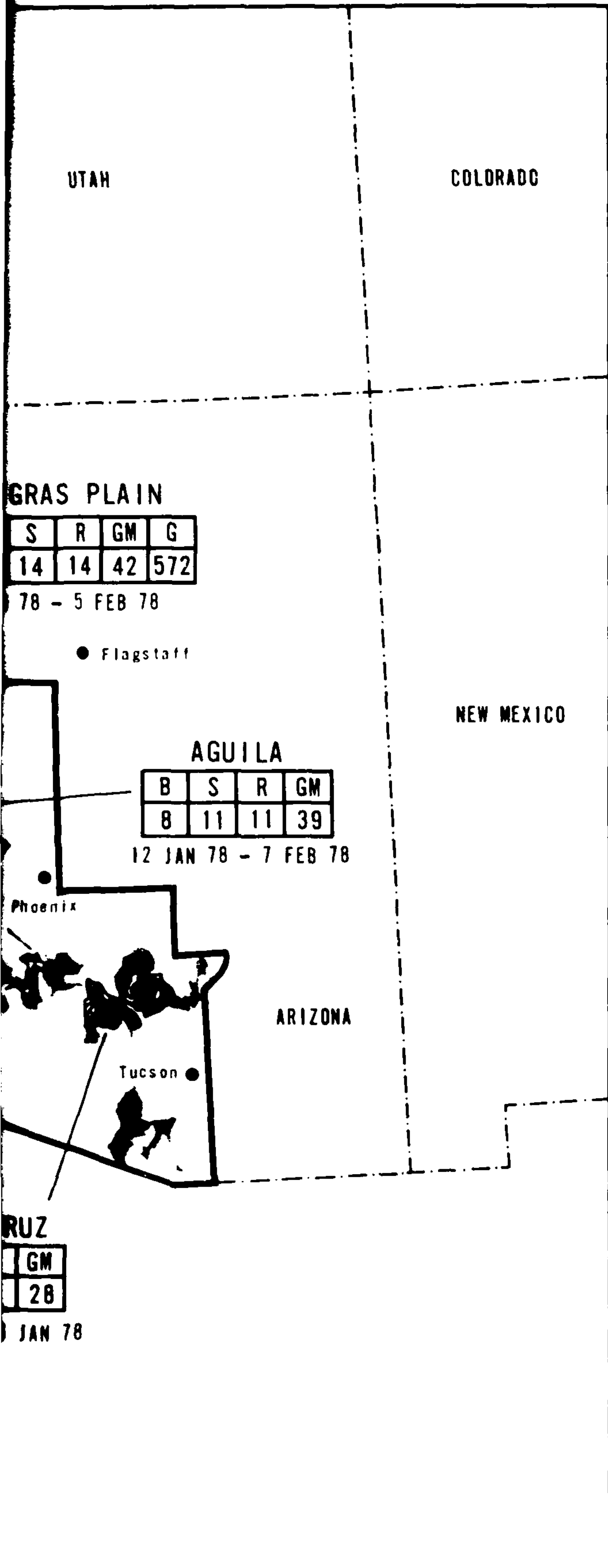

CALIFORNIA
NEVADA
UTAH
MOJAVE
B T S R GM G
10 10 14 14 51 660
20 FEB 78 - 13 MAR 78
Las Vegas
RANEGRAS P
B T S R
16 10 14 14
9 JAN 78 - 5 F
SONORAN
San Bernardino
Indio
Phoenix
El Centro
Yuma
LECHUGUILLA DESERT
B T S DS GM G
39 23 13 4 193 241
LUKE (including Lechuguilla Desert)
B T S DS GM G
89 37 33 6 398 874
14 MAR 77 - 27 JUN 77
SANTA CRUZ
B S R GM
4 8 7 28
9 JAN 78 - 26 JAN 78



EXPLANATION

B - BORINGS

T - TRENCHES

S - SHALLOW SEISMIC REFRACTION LINES

DS - DEEP SEISMIC REFRACTION LINES

R - ELECTRICAL RESISTIVITY LINES

GM - GEOLOGIC RECON MAPPING STATIONS

G - GRAVITY STATIONS

B	T
18	17

— Activity
— Quantity of each activity

SUITABLE AREA

PRIME SITE

SUPPLEMENTAL SITE

0 50 100 150 200
NAUTICAL MILES

0 50 100 150 200
STATUTE MILES

0 50 100 150 200
KILOMETERS

CHARACTERIZATION SITES
AND FIELD ACTIVITIES
SONORAN CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE
3.5-2

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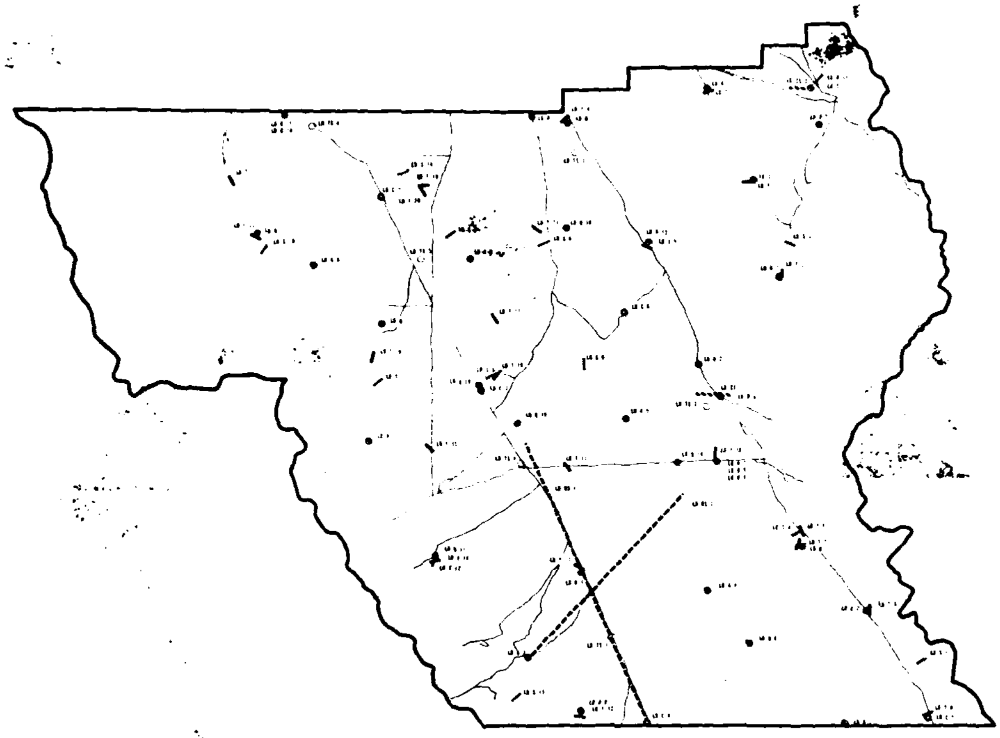
and the Gila Mountains to the west. Field activities for the Characterization study are identified in Figure 3.5-3. The scope of both field and laboratory activities is presented in Table 3.5-1.

3.5.1 Surficial Geology and Terrain

Alluvial fan deposits of younger, intermediate-younger, and intermediate age are the most abundant surficial geologic units within the characterization site (Figure 3.5-4). Younger alluvial fan deposits cover 68 percent of the suitable area while intermediate-younger and intermediate alluvial fan deposits cover 22 percent. Intermediate alluvial fan deposits occur within ten feet (3 m) of the surface throughout the site.

Younger and intermediate-younger alluvial fan deposits are principally uncemented silty sand. Intermediate and older alluvial fan deposits are moderately to strongly cemented silty, clayey and gravelly sands. The remainder of the valley is composed of fluvial and eolian deposits of sand, and stream terrace deposits of interbedded sand, silt, and clay. These deposits are underlain and interbedded with alluvial fan deposits. Descriptions of all surficial geologic units are presented in Table 3.5-2.

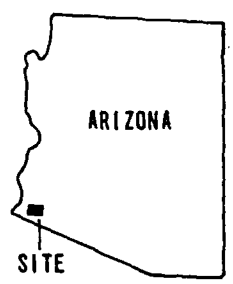
Surface slopes and depths of drainage incision vary with the age of geologic units and distance from the mountain fronts. Maximum surface slope (excluding older alluvial fan deposits) is six percent with typical surface slopes of less than three



1:250,000

1" = 3.2 Nautical Miles
(APPROXIMATE)

SITE LOCATION



For explanation of activity symbols see Drawing 3.5-A.

ACTIVITY LOCATION MAP
LECHUGUILLA DESERT, ARIZONA
SONORAN CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.5-3

FUGRO NATIONAL, INC.

GEOLOGY AND GEOPHYSICS

TYPE OF ACTIVITY	NUMBER OF ACTIVITIES
Geological mapping stations	241
Shallow refraction	13
Deep refraction	4
Downhole velocity	11
Gravity survey	241

ENGINEERING

NUMBER OF BORINGS	DEPTH FEET(METERS)
12	50 (15)
18	100 (30)
6	300 (91)
3	1000 (305)
NUMBER OF TRENCHES	DEPTH FEET(METERS)
23	20 (6)

ENGINEERING-LABORATORY TESTS

TYPE OF TEST	NUMBER OF TESTS
Moisture/density	385
Specific gravity	37
Sieve Analysis	354
Hydrometer	224
Atterberg limits	269
Consolidation	13

TYPE OF TEST	NUMBER OF TESTS
Unconfined compression	50
Triaxial compression	36
Direct shear	44
Compaction	13
CBR	4
Chemical Analysis	18

SCOPE OF FIELD AND LABORATORY ACTIVITIES
LECHUGUILLA DESERT, ARIZONA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE 3.5-1

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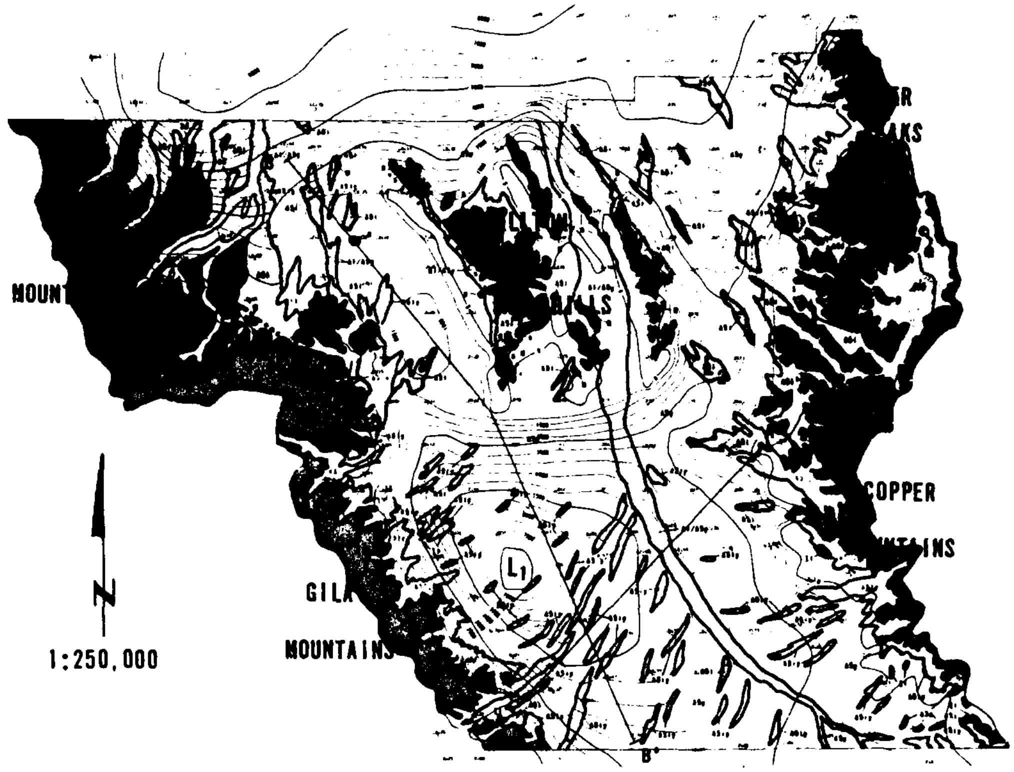


EXPLANATION

SURFICIAL GEOLOGIC UNITS

- A1, A2, A3d and A5y - stream channel, terrace, eolian and younger fan deposits
- A5iy - intermediate-younger fan deposits
- A5i - intermediate fan deposits
- A5o - older fan deposits

ROCK UNITS

- S - Sedimentary
- I1 - Igneous; intrusive
- M - Metamorphic
- Fault, approximately located, dotted where concealed.

SYMBOLS

- A ⊢—⊣ A' — Approximate location of composite Section, See Figure 3.5-6
- — 1000 — — Estimated depth to basement rock, contour interval = 500 feet.
- H_1 — Relative Basement High
- L_1 — Relative Basement Low

NOTE: Basement depths and configuration based on gravity interpretation.

NOTE: For detailed description of geologic units, see Table 3.5-2 and Appendix.

GENERALIZED GEOLOGIC MAP
LECHUGUILLA DESERT, ARIZONA
SONORAN CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.5-4

FUGRO NATIONAL, INC.

ENGINEERING GEOLOGY UNIT (g)	GEOLOGIC AGE	THICKNESS FEET (METERS)	DESCRIPTIVE NAME(S)	USCS SYMBOL(S)	AREAL EXTENT (SIT	
					nm^2 (km^2)	PERCE
Fluvial Deposits (A1)	Quaternary	Unknown	Sand	SP	8 (27)	6
Stream Terrace Deposits (A2)	Quaternary	Unknown	Interbedded Clay, Silt, and Sand	SP,ML,CL	<1	<1
Eolian Deposits, Sheet Sand (A3s)	Quaternary	0–10 (0–3)	Fine Sand	SP	<1	<1
Eolian Deposits, Dune Sand (A3d)	Quaternary	0–10 (0–3)	Sand	SP	<1	<1
Younger Alluvial Fan, Finer-Grained (A5yf)	Quaternary	0–10 (0–3)	Silty Sand	SM	84 (288)	60
Intermediate-Younger Alluvial Fan (A5iy)	Quaternary	Unknown	Silty Sand to Gravel	SM	8 (27)	6
Intermediate-Younger Alluvial Fan, Finer-Grained (A5iyf)	Quaternary	Unknown	Sand to Silty Sand	SM	6 (21)	5
Intermediate-Younger Alluvial Fan, Coarser-Grained (A5iyc)	Quaternary	Unknown	Gravelly Sand	SP	<1	<1
Intermediate Alluvial Fan (A5i)	Quaternary	Unknown	Sand and Gravel	SP	10 (34)	8
Intermediate Alluvial Fan, Finer-Grained (A5if)	Quaternary	Unknown	Sand to Silty Sand	SM	3 (10)	3
Intermediate Alluvial Fan, Coarser-Grained (A5ic)	Quaternary	Unknown	Gravelly Sand to Sandy Gravel	SP	2 (7)	1
Older Alluvial Fan, Coarser-Grained (A5oc)	Quaternary-Tertiary	Unknown	Sandy Gravelwith Cobbles	GP	3 (10)	3

NOTES:

(a) Generally mixed with A5y deposits; designated A1/A5y on Figure 3.5-4.
(b) Depicted on Drawing 3.5-B
(c) Included in unit A5y on Figure 3.5-4.
(d) Included in unit A5iy on Figure 3.5-4.
(e) Included in unit A5i on Figure 3.5-4.
(f) Included in unit A5o on Figure 3.5-4.
(g) For generic description of geologic units, see Appendix.

EXTENT (SITE)		PROPERTIES OF SURFACE MATERIALS					SURFACE MORPHOLOGY		NOTES
km^2)	PERCENT	GRADATION	CEMENTATION	MAXIMUM GRAIN SIZE	PAVEMENT/ PATINA	STAGE OF CALICHE	SLOPE (PERCENT)	DRAINAGE DEPTHS FEET(METERS)	
7)	6	Poor	None–Weak	Boulder	None None	None	≤1	0–4 (0–1.2)	(a)
1	<1	Poor	Moderate	Gravel	Well Fair	None–II	Not Applicable	Not Applicable	
1	<1	Poor	Moderate	Sand	Poor None	I–II	No Data	5 (1.5)	(b)
1	<1	Poor	None	Sand	None None	None	Not Applicabe	None	
(288)	68	Moderately well	None–Weak	Cobble	None None	None–II	<1–2	0–3 (0–1)	(c)
(27)	6	Moderately well	Weak	Boulder	Poor–Fair/ None–Poor	None–II	1–3	1–20 (0.3–6)	
(21)	5	Moderately well	None–Weak	Cobble	Poor–Fair/ None	None–II	1–3	1–8 (0.3–2.4)	(b), (d)
<1	<1	Moderately well	None–Weak	Boulder	Poor/ Poor–None	I	No Data	No Data	(b), (d)
(34)	8	Moderately well	Moderate–Strong	Boulder	Well Fair–Well	II	1–2	0–20 (0–6)	
(10)	3	Moderately well	Weak–Moderate	Cobble	Fair–Well None–Poor	II	1–3	1–7 (0.3–2)	(b), (e)
2 (7)	1	Moderately well	Weak–Moderate	Boulder	Fair–Well/ Fair–Well	II	2–6	4–20 (1.2–6)	(b), (e)
(10)	3	Moderately well	Moderate–Strong	Boulder	None–Well/ Poor–Well	II–III	Not Applicable	10–130 (3–40)	(b), (f)

DESCRIPTION OF SURFICIAL GEOLOGIC UNITS LECHUGUILLA DESERT, ARIZONA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

TABLE 3.5-2

FUGRO NATIONAL, INC.

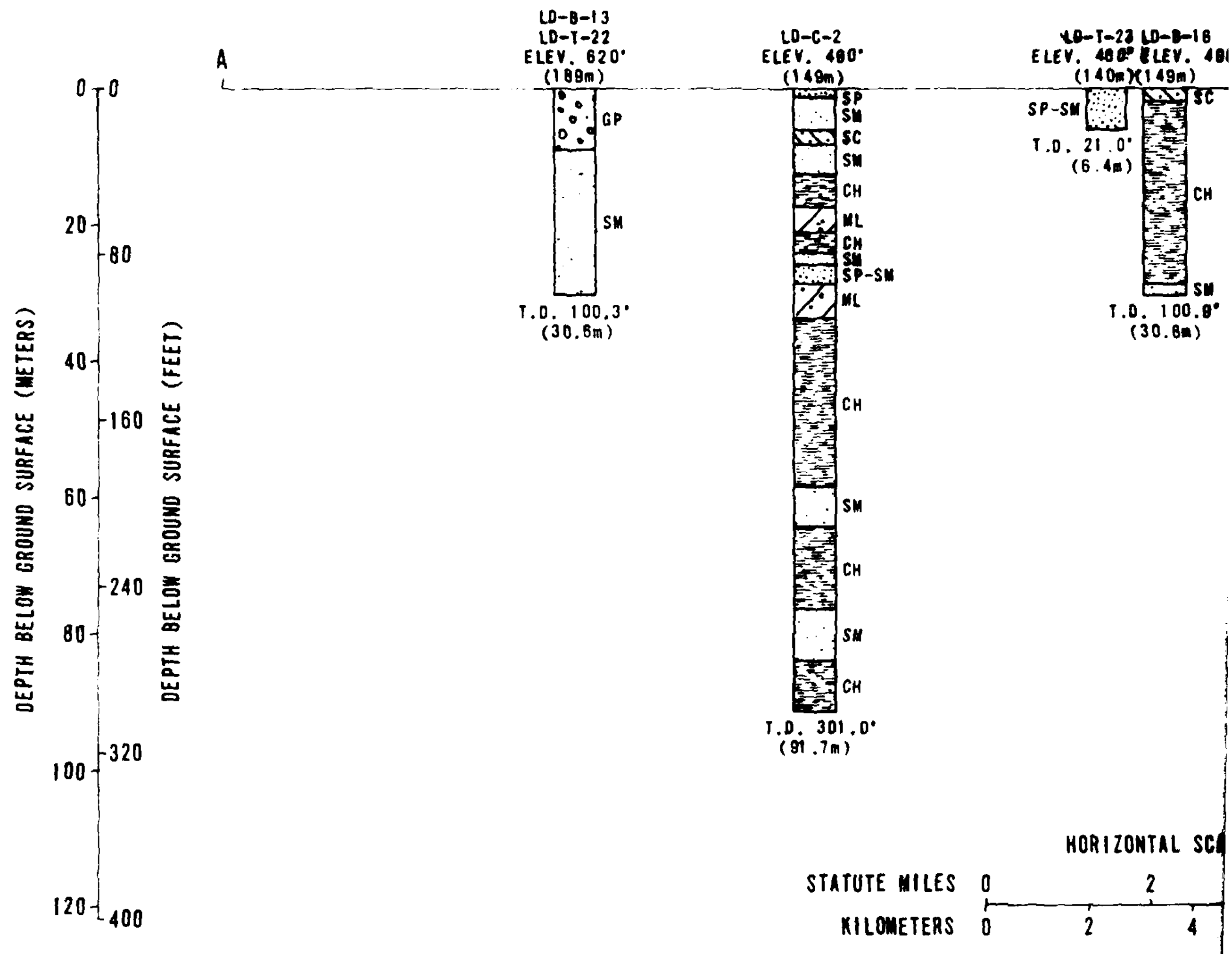
percent. Maximum depth of incision is 14 feet (4 m) with typical depths of five feet (1.5 m) or less.

3.5.2 Subsurface Conditions

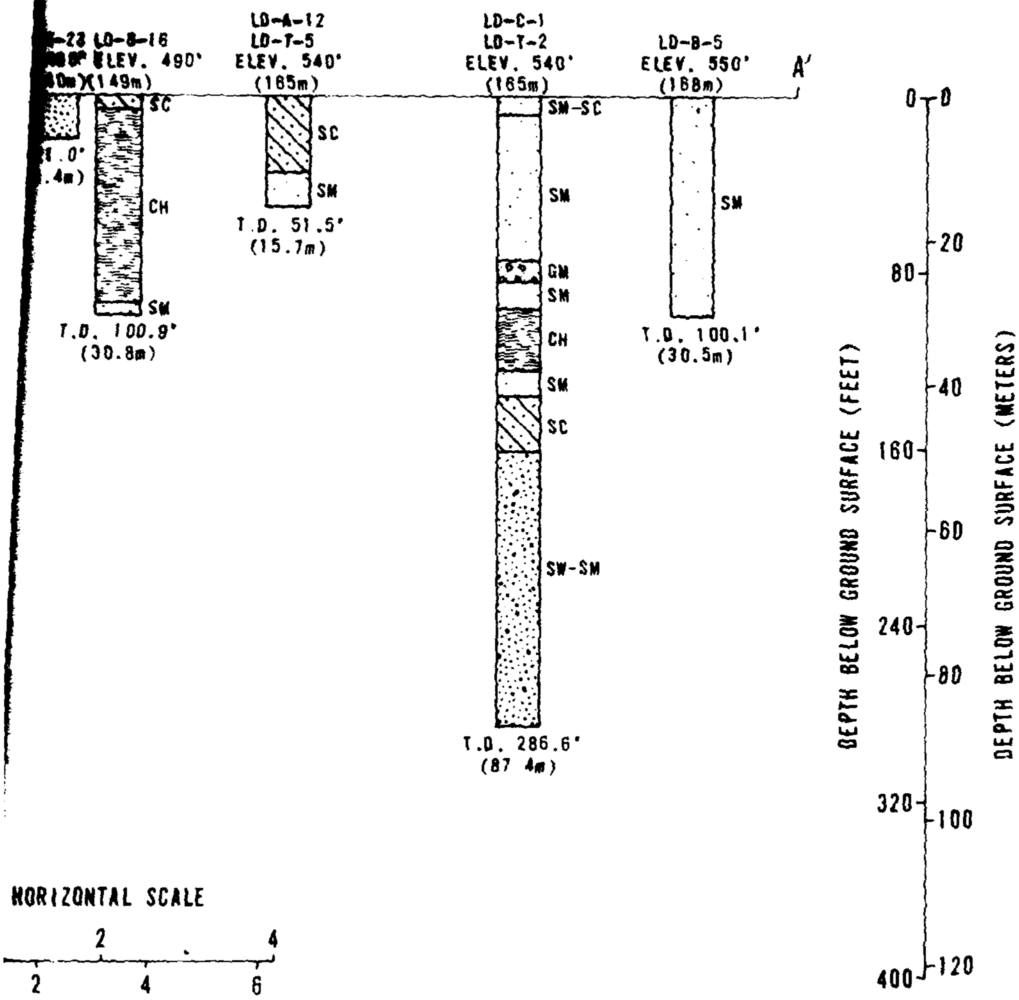
The subsurface deposits of Lechuguilla Desert consist predominantly of silty and clayey sands. A typical section of the valley is illustrated by the soil profile in Figure 3.5-5. Percentage of fines within these sand deposits generally increases toward the central portion of the valley. The percentage of cobbles and boulders increases toward the mountain fronts, but is generally less than ten percent. Clay deposits are not encountered at the surface, but are present in the subsurface at the northern and eastern portions of the valley.

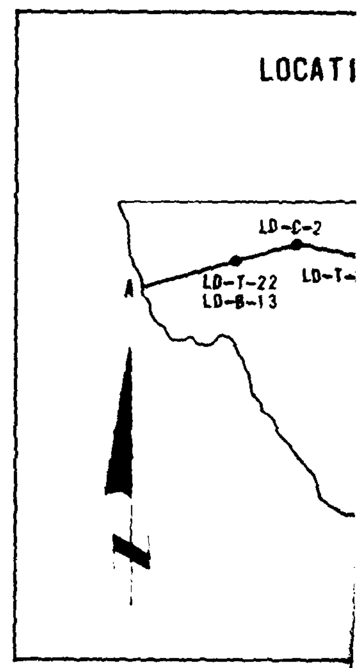
Geophysical investigations indicate shallow bedrock near the mountain fronts and deeper bedrock near the valley axis. Gravity survey data indicate the greatest depth to rock to be approximately 7500 feet (2300 m) in the area of the intersection of generalized cross sections A-A' and B-B' (Figure 3.5-6, designated L1 in Figure 3.5-4). The basin is bounded on the east, west, and north by steep gradients in basement topography typical of those associated with normal faults. North of the basin is a buried basement ridge extending east and west from the Wellton Hills to the mountains surrounding the valley. The depth to the ridge is 2000 feet (600 m) to the east and 1000 feet (300 m) to the west of the Wellton Hills. Basement depths north of the ridge reach 5000 feet (1500 m).

Ground water occurs at depths exceeding 50 feet (15 m) throughout



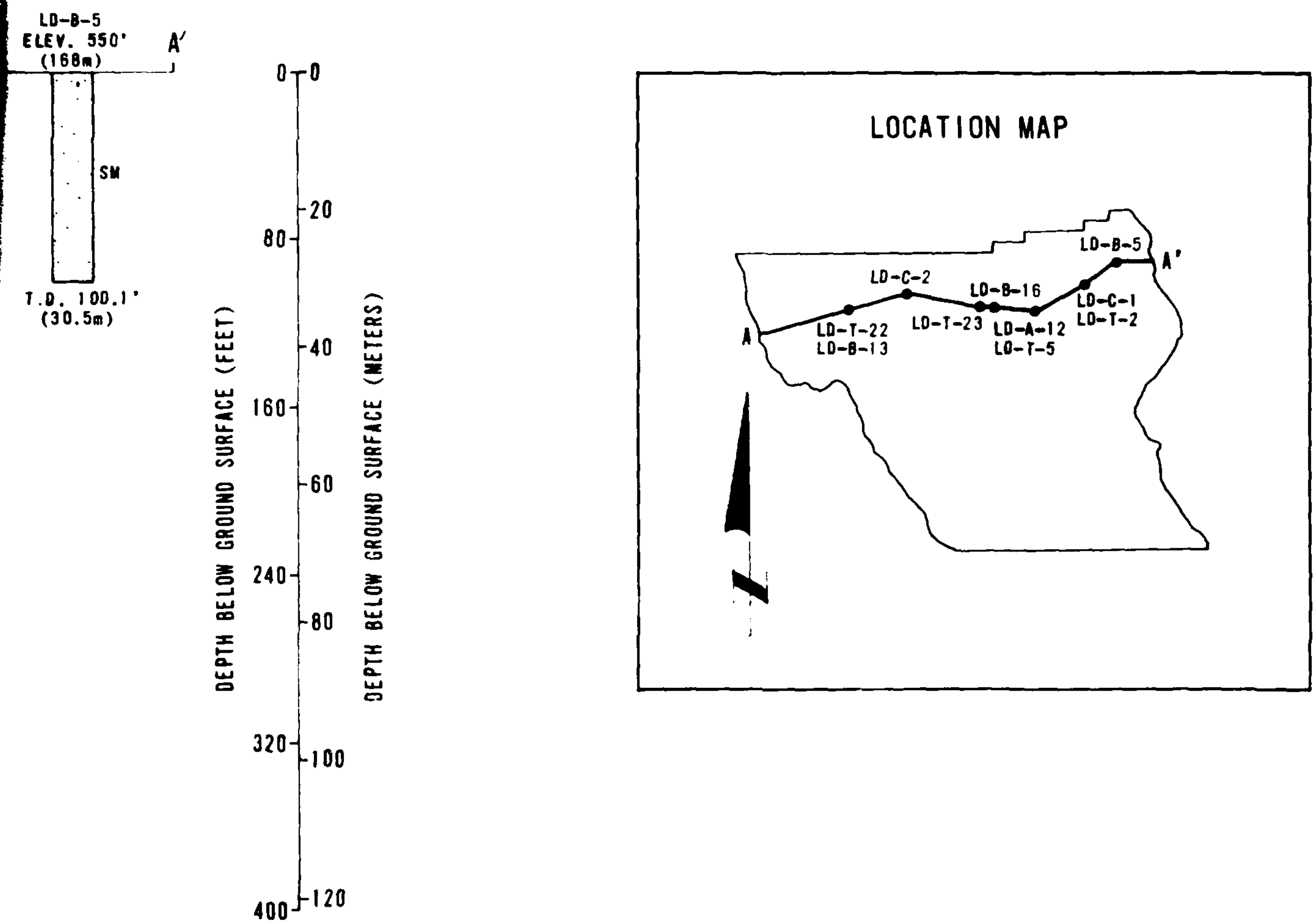
NOTES: 1. Ground surface elevations shown at locati
2. T.D.=Total Depth
3. Soil types shown adjacent to soil column a
(USCS) and are explained in the appendix





wn at locations of borings are approximate

soil column are based on Unified Soil Classification System
the appendix



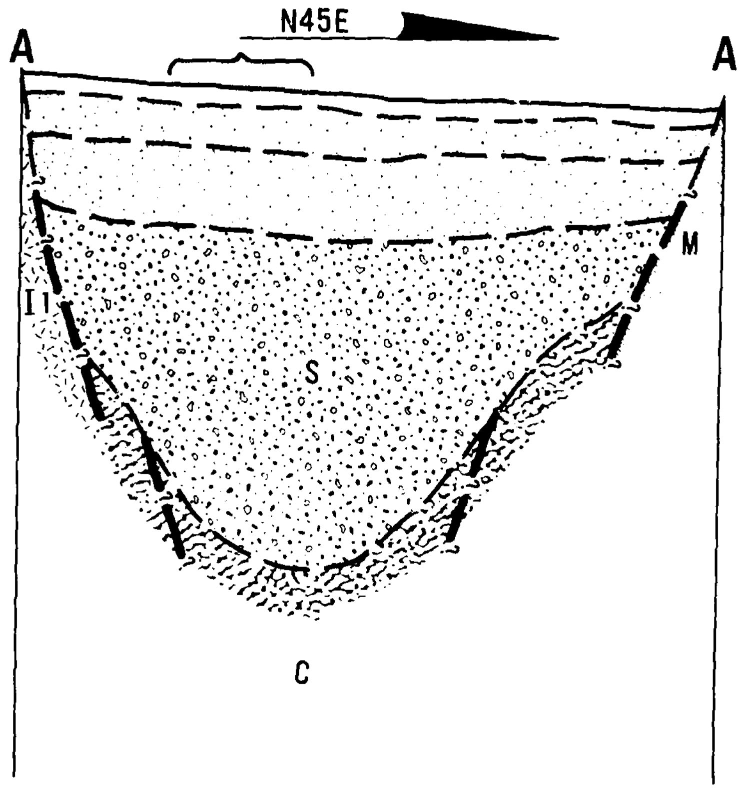
tion System

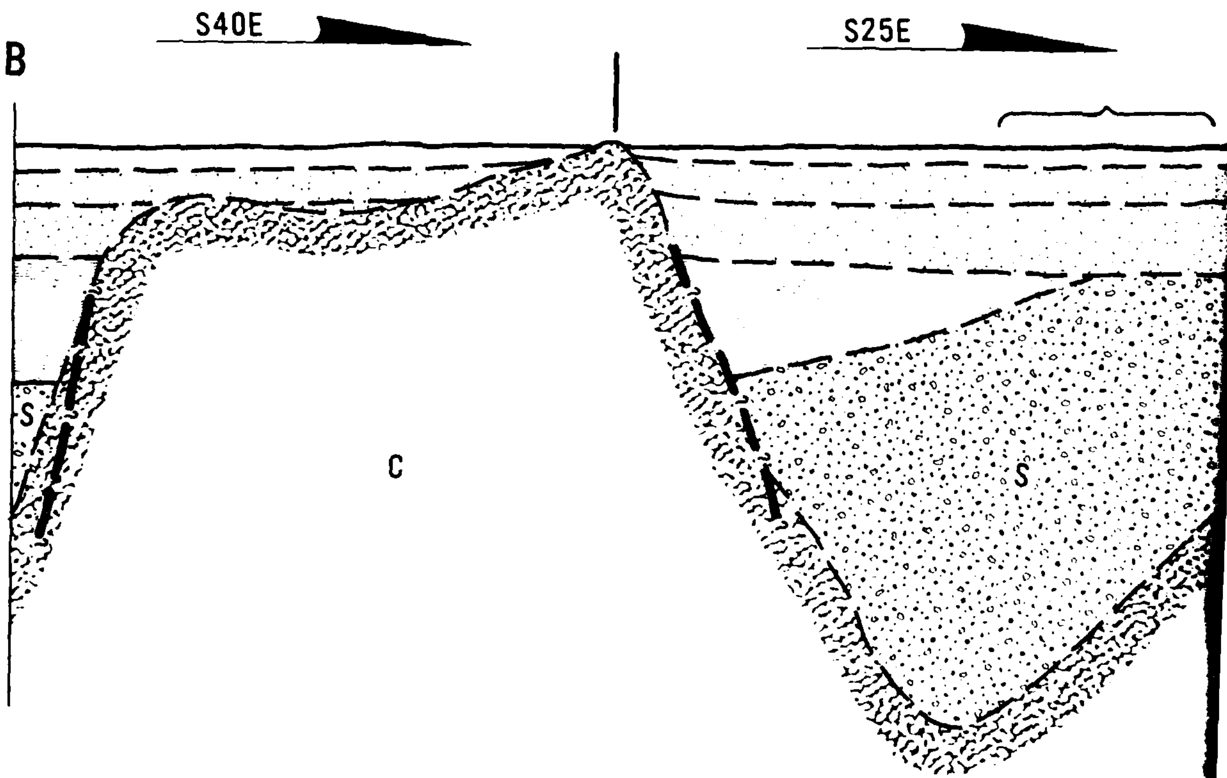
SOIL PROFILE
LECHUGUILLA DESERT, ARIZONA
SONORAN CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
3.5-5

FUGRO NATIONAL, INC.


N45E
A
A'
M
I
S
C


S40E
S25E
B
S
C
S

EXPLANATION

SURFICIAL BASIN FILL; Alluvial fans and playa lacustrine deposits; average seismic velocity 2650-3400 fps (800-1100 mps).

LACUSTRINE/MARINE; Older material not exposed at the surface; average seismic velocity 3500-5000 fps (1050-1600 mps).

OLDER BASIN FILL; Well indurated alluvial and colluvial material; average seismic velocity 6900-7500 fps (2150-3350 mps).

OLDER BASIN FILL; Very well indurated alluvial and possibly marine deposits; average seismic velocity 9700 fps (3050 mps).

SEDIMENTARY ROCK (S)

INTRUSIVE IGNEOUS ROCK (I1)

METAMORPHIC ROCK (M)

IGNEOUS/METAMORPHIC ROCK COMPLEX (C)

APPROXIMATE VERTICAL SCALE

FEET 0, 1000, 2000, 3000, 4000

METERS 0, 400, 800, 1200

Approximate geologic contact.

Fault; Geophysical interpretation.

Zone of Aeromagnetic Anomaly may indicate shallow igneous rock; exact configuration unkown.

NOTES:

(1) Approximate cross section locations shown on Figure 3.5-4
(2) Basement profiles from Drawing 3.5-D
(3) Seismic velocities determined from deep seismic refraction lines.

APPROXIMATE HORIZONTAL SCALE

MILES 0 2 4

KILOMETERS 0 2 4 6

GENERALIZED GEOLOGIC CROSS SECTIO
LECHUGUILLA DESERT, ARIZONA
SONORAN CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGU 3.5

UGRO NATIONAL, IN

the valley. Ground water at depths less than 150 feet (46 m) occurs only in the northwestern corner north of the Wellton Hills. Depths to water gradually increase southward from 150 feet (46 m) in the northwest to more than 400 feet (122 m) in the south. This is based on information from four borings completed during site investigation.

3.5.3 Engineering and Geophysical Properties

Younger, intermediate and older alluvial fans are the predominant geologic units of Lechuguilla Desert. Their engineering and geophysical properties are summarized in Table 3.5-3 and Figure 3.5-7. Younger, intermediate-younger and intermediate alluvial fan units were combined due to their similar grain size and other similar engineering characteristics. The soils in the unit are predominantly silty and clayey sands which have low compressibility and moderately high shear strengths.

The older alluvial fan deposits are encountered in the northwestern portion of the valley and cover a relatively small portion of Lechuguilla Desert. The unit is generally coarser than the younger and intermediate alluvial fan units and is strongly cemented. The gravel content generally exceeds 50 percent.

3.5.4 Conclusions

The following favorable and unfavorable geotechnical conditions for deployment of the MX system at Lechuguilla Desert are based on the results of the Characterization study.

ENGINEERING AND GEOPHYSICAL PROPERTIES	Intermediate and younger alluvial fan deposits (A5i and A5y)	Older alluvial fan de
UNIFIED SOIL CLASSIFICATION SYMBOL(S)	SM, SC, GP, ML, CL	GP, GM, S
GENERAL PROPERTIES		
DRY DENSITY pcf(kg m^3)	95-124 (1522-1986)	DNA
MOISTURE CONTENT (%)	0 2-12 5	DNA
DEGREE OF SATURATION (%)	17-86	DNA
SPECIFIC GRAVITY	2 64-2 77	DNA
DEGREE OF CEMENTATION	Uncemented to moderate	Moderate to s
COMPRESSIONAL WAVE VELOCITIES fps(mps)	1100-4600 (335-1402)	DNA
ELECTRICAL CONDUCTIVITY (mhos m)	DNA	DNA
GRAIN SIZE DISTRIBUTION (%)		
BOULDERS >12 inches(30cm)	0-20	0-50
COBBLES 3 to 12 inches(8to 30cm)	0-40	0-60
GRAVEL	0-70	30-60
SAND	25-95	30-55
SILT AND CLAY	5-75	5-15
PLASTICITY DATA		
LIQUID LIMIT	24-53	DNA
PLASTICITY INDEX	NP-27	DNA
COMPRESSIBILITY DATA		
COMPRESSION AT 4 ksf(192kN/m^2) (%)	1 5-3	DNA
SWELL OR COLLAPSE UPON SATURATION (%)	0-3 (Collapse)	DNA
SHEAR STRENGTH DATA		
UNCONFINED COMPRESSION ksf(kN m^2)	0.2-4.8 (10-230)	DNA
CD TRIAXIAL COMPRESSION	c = 0.1-0.2 ksf (5-10 kn m^2). φ = 32-39°	DNA
DIRECT SHEAR ksf(kN m^2)	0.9-10.6 (43 to 508)	DNA
COMPACTION AND CBR DATA		
MAXIMUM DRY DENSITY pcf(kg m^3)	128.8-134.7 (2063 to 2158)	134 ± (21
OPTIMUM MOISTURE CONTENT (%)	7.0-9.6	8.1 ±
CBR AT 90% RELATIVE COMPACTION	10-40	DNA

DNA = DATA NOT AVAILABLE (INSUFFICIENT DATA OR TESTS NOT PERFORMED)

GEOLOGIC UNITS	
alluvial fan deposits (A5o)	
GP, GM, SM	
DNA	
DNA	
DNA	
DNA	
Moderate to strong	
DNA	
DNA	
0-50	
0-60	
30-60	
30-55	
5-15	
DNA	
DNA	
DNA	
DNA	
DNA	
DNA	
DNA	
134 ± (2146 ±)	
8.1 ±	
DNA	

RANGE OF ENGINEERING AND GEOPHYSICAL PROPERTIES
LECHUGUILLA DESERT, ARIZONA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

TABLE 3.5-3

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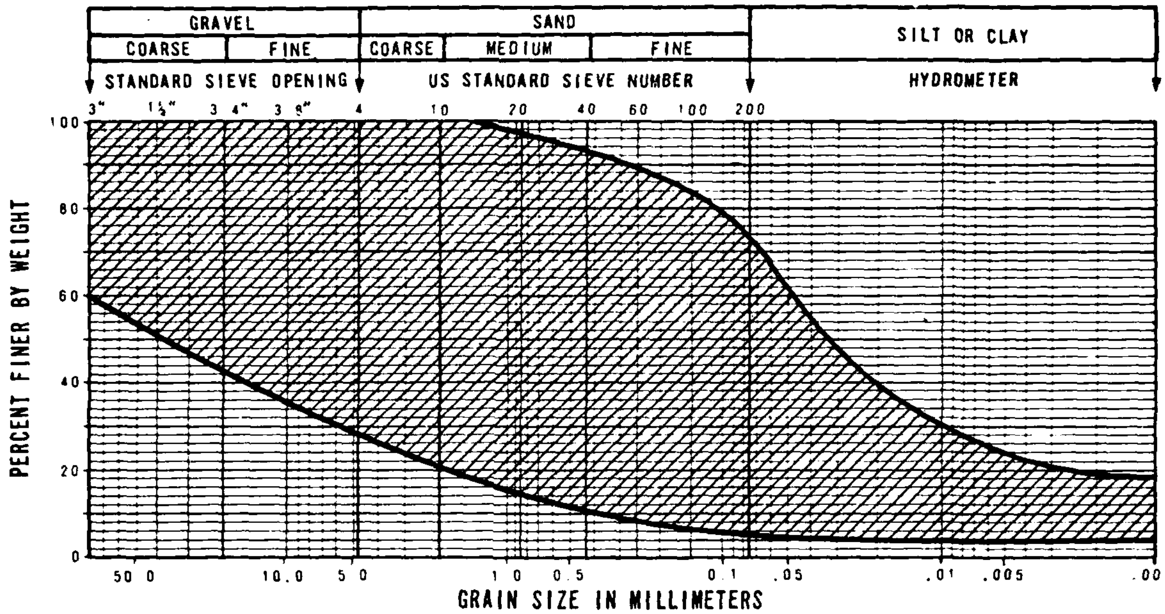
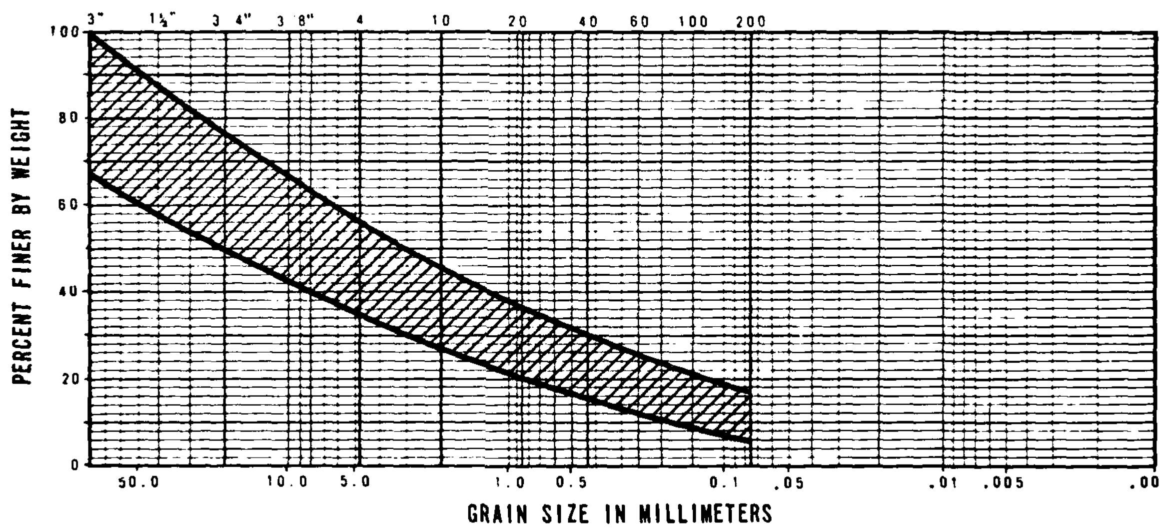


A5



A5o

RANGE OF GRADATION OF GEOLOGIC UNITS
LECHUGUILLA DESERT, ARIZONA
SONORAN CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
3.5-7

FUGRO NATIONAL, INC.

Favorable conditions:

- Surface slope is less than three percent over 90 percent of the area, therefore, little preconstruction grading will be required.
- Drainage incisions are typically less than three feet (1 m) deep within the central valley area, therefore major drainage structures will generally not be required.
- Surficial soils have good support characteristics as subgrade for roads.
- Soils are generally suitable for: excavation of vertical shelters using an auger, continuous trenches using an MX trencher, and horizontal shelters using conventional excavation methods.
- Sufficient quantities of aggregate and water required for roads and concrete are available within and/or adjacent to the site area.
- Depth to rock over most of the site is expected to be greater than 150 feet (46 m).
- Depth to ground water is greater than 150 feet (46 m) in approximately 80 percent of the valley, and generally ranges from 150 to 400 feet (46 to 122 m).
- Land is administered by BLM and DoD.

Unfavorable conditions:

- o No regular network of paved or unpaved roads exists and construction of new roads will be required.
- o Existing wells are insufficient to provide the water needed for construction and additional wells will be required.

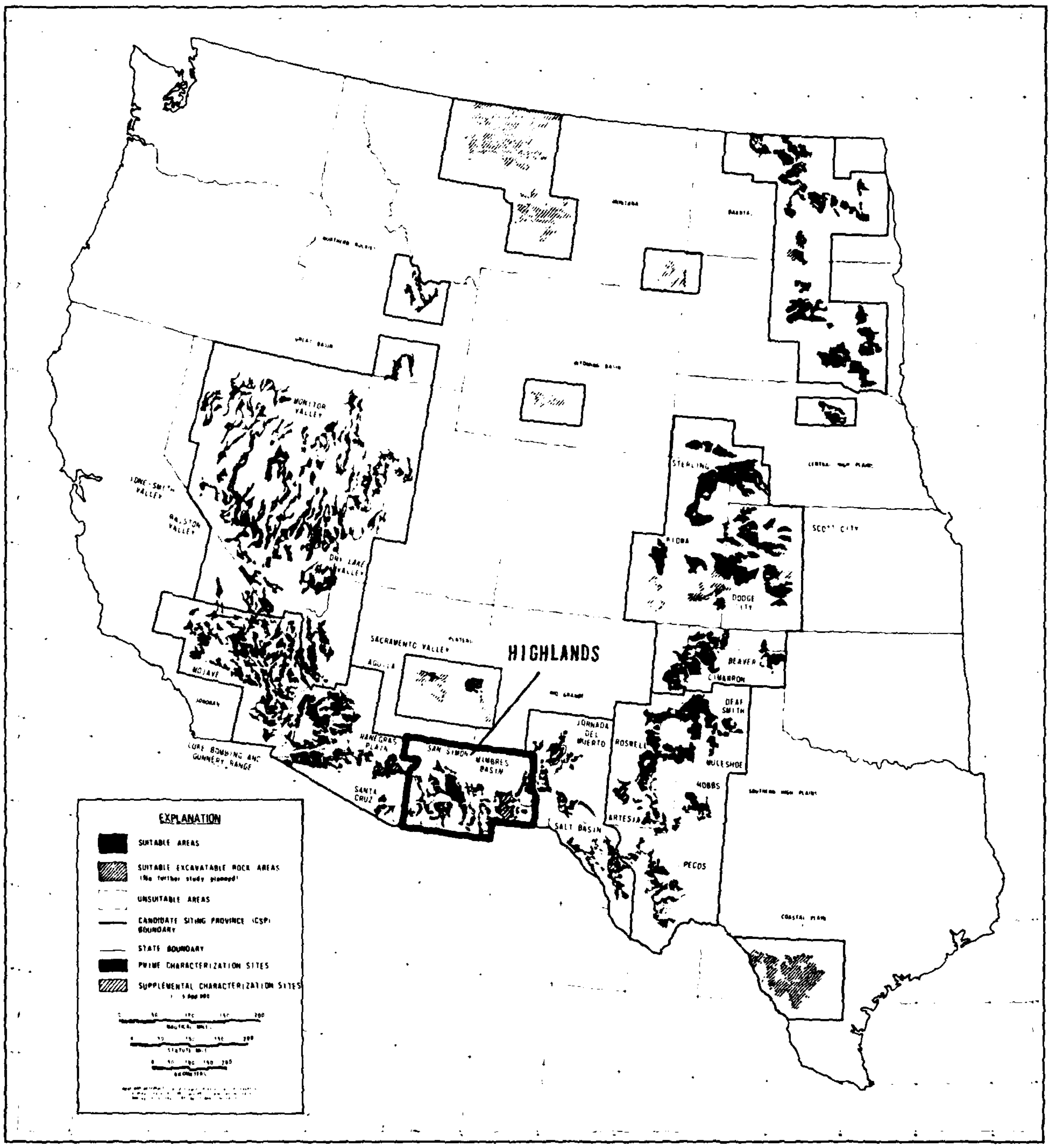
In summary, the Lechuguilla Desert characterization site presents favorable geotechnical conditions for deployment of the present MX basing mode concepts.

3.6 SAN SIMON SITE: HIGHLANDS CSP

The Highlands CSP lies within the Mexican Highlands section of the Basin and Range physiographic province and covers portions of New Mexico and Arizona (Figure 3.6-1). Approximately 57 percent of the CSP is privately owned with federal and state agencies controlling 26 and 17 percent of the remaining area, respectively. The estimated land use is 93 percent rangeland and seven percent irrigated farmland.

The CSP is characterized by north to northwest trending mountain ranges separated by fault controlled intermontane basins possessing a variety of geologic and engineering conditions. Two sites were selected to characterize geotechnical conditions in the CSP (Figure 3.6-2) based upon a review of regional geologic and engineering literature. Results of the San Simon Valley investigation are presented to provide a sampling of geotechnical conditions encountered in the Highlands CSP, particularly those present in Arizona.

The San Simon site covers an area of 715 nm^2 (2452 km^2) within Graham and Cochise Counties, Arizona. The site occupies a broad alluvial basin bounded by mountain ranges to the east and west and open to the Gila River to the north. Field activities for the Characterization study are identified in Figure 3.6-3. The scope of both the field and laboratory activities is presented in Table 3.6-1.

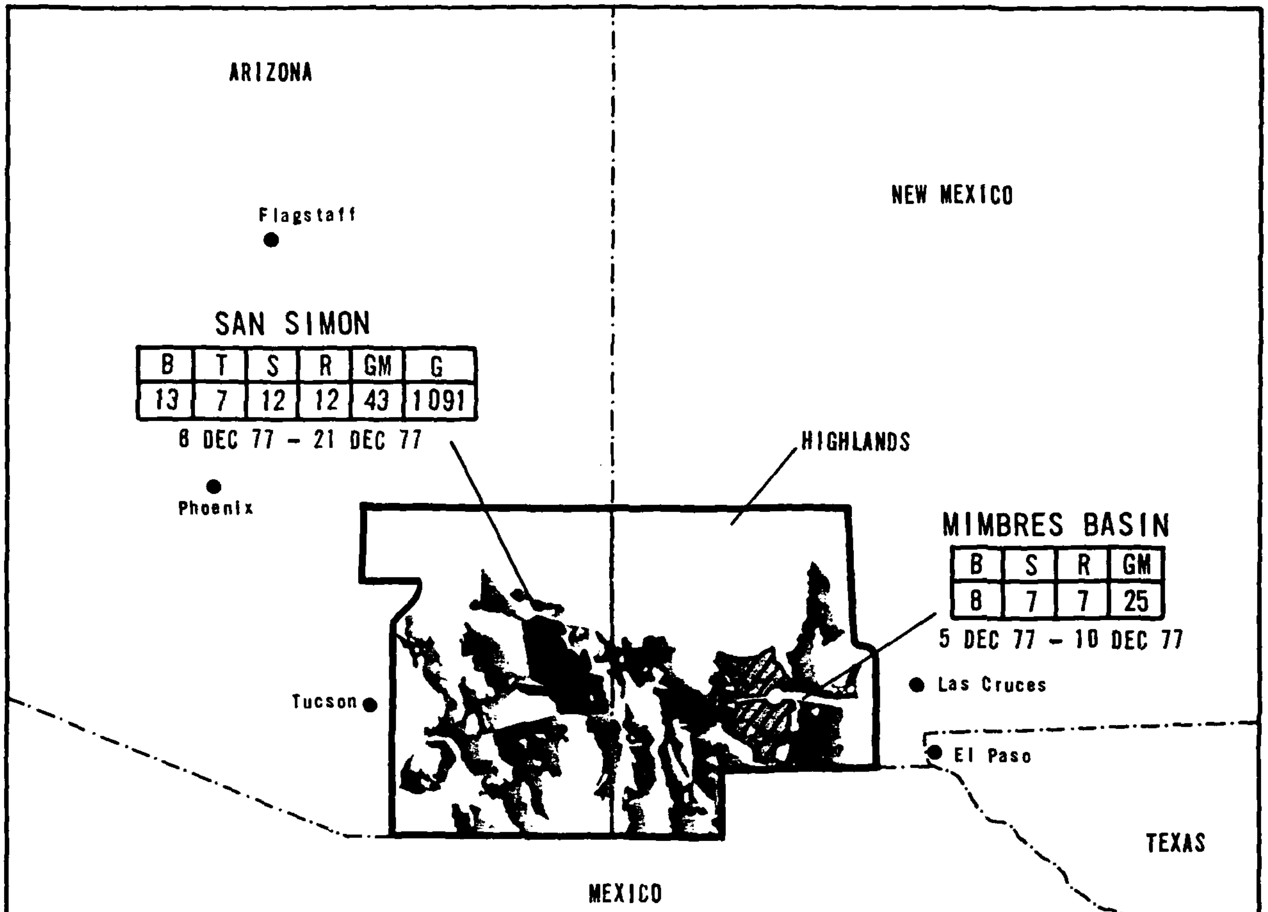


LOCATION OF HIGHLANDS CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.6-1

FUGRO NATIONAL, INC.



EXPLANATION

B - BORINGS
T - TRENCHES
S - SHALLOW SEISMIC REFRACTION LINES
R - ELECTRICAL RESISTIVITY LINES
GM - GEOLOGIC RECON MAPPING STATIONS
G - GRAVITY STATIONS

SUITABLE AREA

PRIME SITE

SUPPLEMENTAL SITE

B	T
17	18

— Activity
— Quantity of each activity

0 50 100 150 200
NAUTICAL MILES

0 50 100 150 200
STATUTE MILES

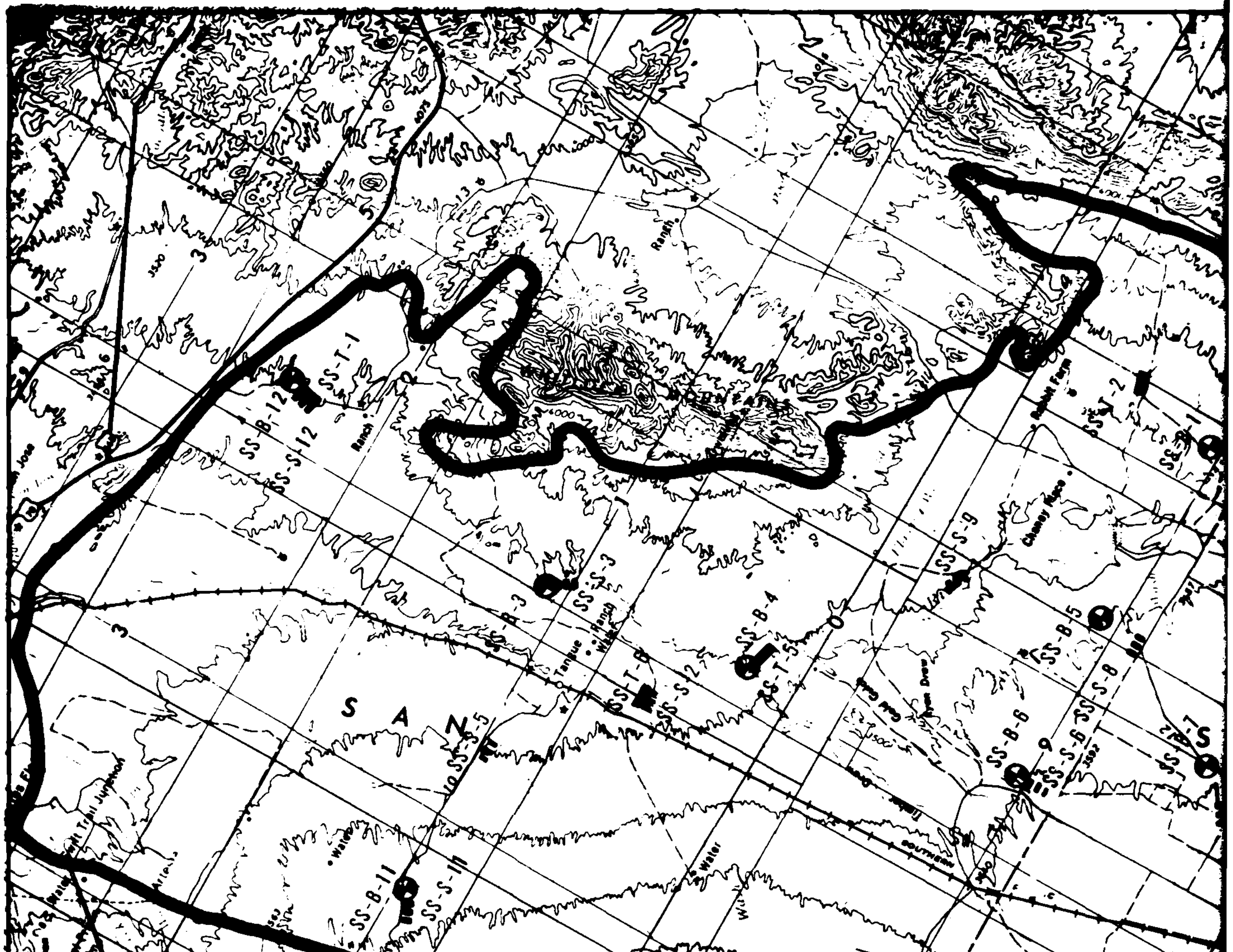
0 50 100 150 200
KILOMETERS

CHARACTERIZATION SITES AND FIELD ACTIVITIES HIGHLANDS CSP

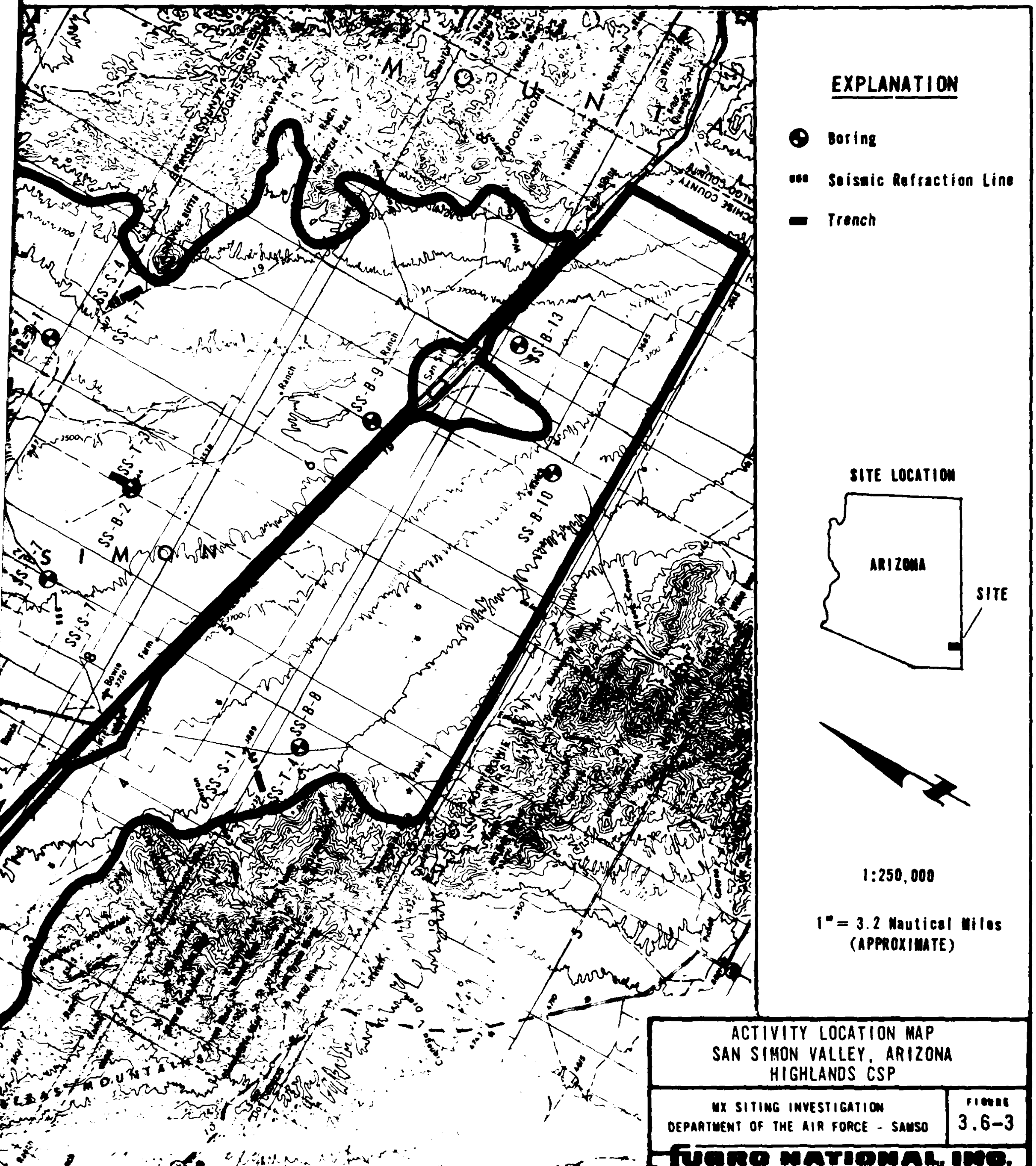
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.6-2

FUGRO NATIONAL, INC.



SS-T-1
SS-B-12
SS-S-12
SS-S-3
SS-B-4
SS-T-5
SS-S-2
SS-T-6
S A N
SS-S-5
SS-B-11
SS-S-11
SS-S-9
SS-B-5
SS-S-8
SS-B-6
SS-S-6
SS-T-2
Ranch
Water



ACTIVITY LOCATION MAP
SAN SIMON VALLEY, ARIZONA
HIGHLANDS CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.6-3

FUGRO NATIONAL, INC.

GEOLOGY AND GEOPHYSICS

TYPE OF ACTIVITY	NUMBER OF ACTIVITIES
Geological mapping stations	43
Shallow refraction	12
Electrical resistivity	12

ENGINEERING

NUMBER OF BORINGS	DEPTH FEET(METERS)
11	50(15)
1	100(30)
1	300(91)
NUMBER OF TRENCHES	**DEPTH FEET(METERS)**
7	12 (4)

ENGINEERING-LABORATORY TESTS

TYPE OF TEST	NUMBER OF TESTS
Moisture/density	135
Specific gravity	4
Sieve analysis	66
Hydrometer	50
Atterberg limits	37
Consolidation	4

TYPE OF TEST	NUMBER OF TESTS
Unconfined compression	12
Triaxial compression	7
Direct shear	18
Compaction	6
CBR	2
Chemical analysis	6

SCOPE OF FIELD AND LABORATORY ACTIVITIES
SAN SIMON VALLEY, ARIZONA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE 3.6-1

FUGRO NATIONAL, INC.

3.6.1 Surficial Geology and Terrain

Alluvial fan deposits are the most abundant surficial geologic materials and are typically present to depths of 20 feet (6 m) or greater over 59 percent of the San Simon site (Figure 3.6-4). Younger and intermediate age alluvial fans covering approximately 35 and 25 percent of the area, respectively, have been delineated. Exposed older (Plio-Pleistocene) lacustrine deposits cover 30 percent of the surface but may be extensive in the subsurface.

The alluvial fan deposits are typically clayey and silty sands with gravel ranging from sandy gravel with cobbles and boulders near the mountains to sandy silts near the basin axis. Older lacustrine deposits consist of clay and silt in the axial portion of the basin; and gravel, cobbles and boulders near the mountain fronts. These three units along with the remaining surficial units are described in Table 3.6-2.

Surface slopes and depths of drainage incision vary with geologic units, both generally increasing towards the mountain fronts. Most of the alluvial fan deposits have maximum surface slopes of less than three percent and depths of incision of less than six feet (2 m). The older lacustrine deposits in the northeastern portion of the valley are dissected into a badlands-type topography and commonly have ten feet (3 m) or more of incision.

3.6.2 Subsurface Conditions

Varying thicknesses of younger and intermediate alluvial fan

EXPLANATION

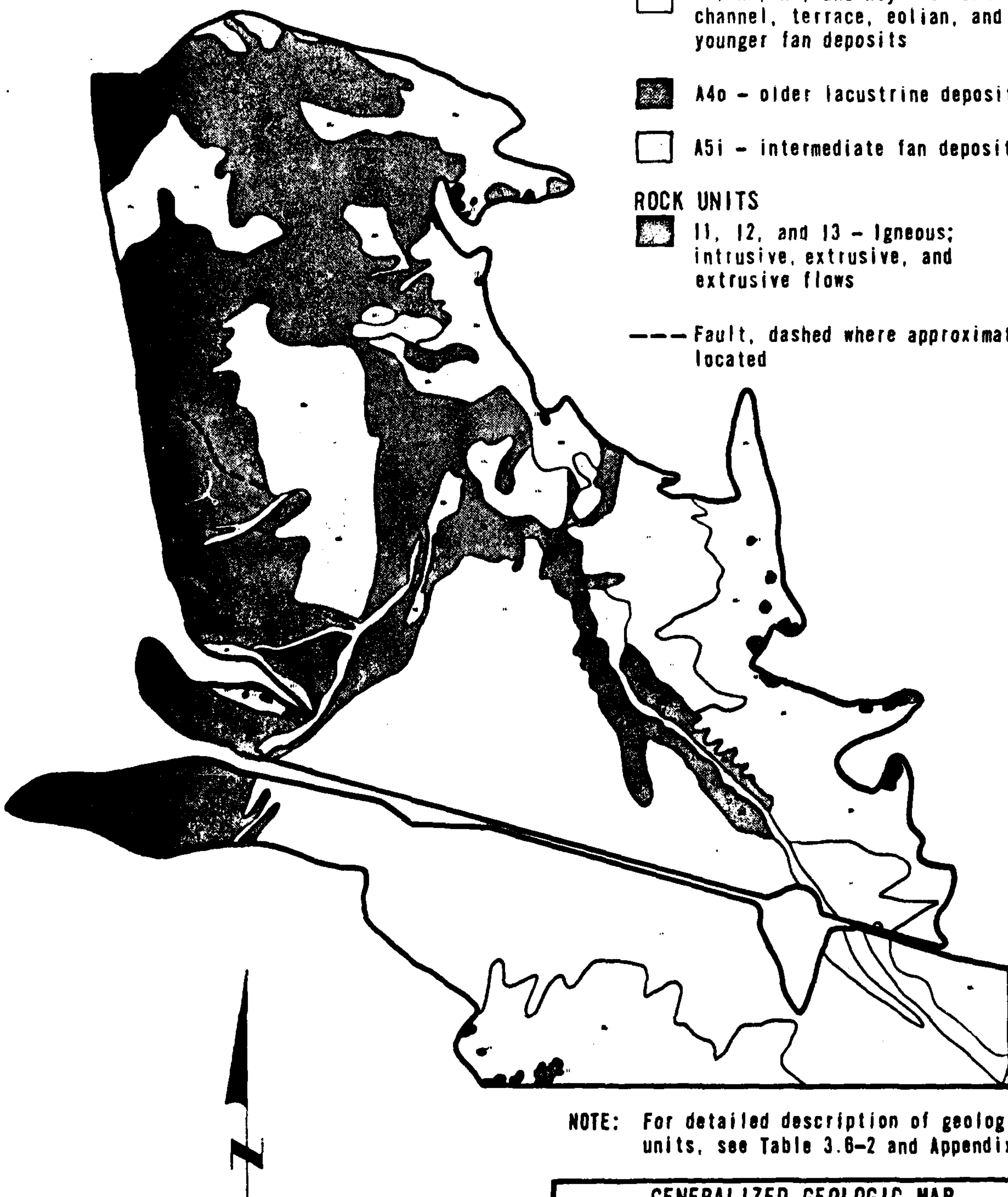
SURFICIAL GEOLOGIC UNITS

- A1, A2, A3, and A5y - stream channel, terrace, eolian, and younger fan deposits
- A4o - older lacustrine deposits
- A5i - intermediate fan deposits

ROCK UNITS

- I1, I2, and I3 - Igneous; intrusive, extrusive, and extrusive flows

--- Fault, dashed where approximately located



1:400,000
(approximate)

NOTE: For detailed description of geologic units, see Table 3.6-2 and Appendix.

GENERALIZED GEOLOGIC MAP
SAN SIMON, ARIZONA
HIGHLANDS CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE 3.6-4

FUGRO NATIONAL, INC.

ENGINEERING GEOLOGY UNIT (d)	GEOLOGIC AGE	THICKNESS FEET (METERS)	DESCRIPTIVE NAME(S)	USCS SYMBOL(S)	AREAL EXTENT (SITE)	
					nm^2 (km^2)	PERCENT
Older Fluvial Deposits (A1o)	Quaternary	Unknown	Gravelly Sand with Silt, Silty Clay with Gravel	SP-SW, CH	14 (48)	2
Stream Terrace Deposits (A2s)	Quaternary-Tertiary	Unknown	Sandy Gravel	GW	7 (24)	1
Eolian Deposits, Sheet Sand (A3s)	Quaternary	Unknown	Sand and Silt	SM, ML	50 (172)	7
Older Lacustrine Deposits (A4o)	Quaternary-Tertiary	Unknown	Clay, Silt, Sand, Gravel with cobbles and boulders	CL, ML, SP-SW, GP-GW	215 (737)	30
Younger Alluvial Fan Deposits (A5y)	Quaternary	Unknown	Silty sand, Sand with Gravel	SM, SP	243 (833)	35
Intermediate Alluvial Fan Deposits (A5i)	Quaternary	Unknown	Silty Sand with Gravel	SM	179 (614)	25

NOTES:

(a) Minor amounts of A1 have been combined with A1o in Figure 3.6-4.

(b) Finer-grained units are dissected into a badland-type topography. Gravel, cobbles and boulders increase toward valley periphery.

(c) Varying thicknesses of these deposits commonly veneer A4o deposits.

(d) For generic description of geologic units, see Appendix.

AREAL EXTENT (SITE)		PROPERTIES OF SURFACE MATERIALS					SURFACE MORPHOLOGY		NOTES
mm^2 (km^2)	PERCENT	GRADATION	CEMENTATION	MAXIMUM GRAIN SIZE	PAVEMENT/ PATINA	STAGE OF CALICHE	SLOPE (PERCENT)	DRAINAGE DEPTHS FEET(METERS)	
14 (48)	2	Poor-Moderately well	Weak-Moderate	Gravel	None/None	I-II	< 1	12-15 (4-5)	(a)
7 (24)	1	Poor	Strong	Boulder	None/None	II-III	< 1	0-5 (0-1.5)	
50 (172)	7	Poor	None-Weak	Sand	None/None	None	≤ 1	0-5 (0-1.5)	
215 (737)	30	Poor	Weak-Strong	Cobble	None/None	I-III	1-2	10-15 (3-5)	(b)
243 (833)	35	Poor-Moderately well	None-Weak	Gravel	None/None	None-I	≤ 1	0-2 (0-0 6)	(c)
179 (614)	25	Well	Weak-Moderate	Boulder	Poor/Poor	None-III	1-3	0-6 (0-2)	(c)

DESCRIPTION OF SURFICIAL GEOLOGIC UNITS
SAN SIMON VALLEY, ARIZONA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

TABLE 3.6-2

FUGRO NATIONAL, INC.

deposits typically overlie several hundred feet of older lacustrine deposits in San Simon Valley. The composition of the soils with depth is illustrated by the soil profile shown in Figure 3.6-5.

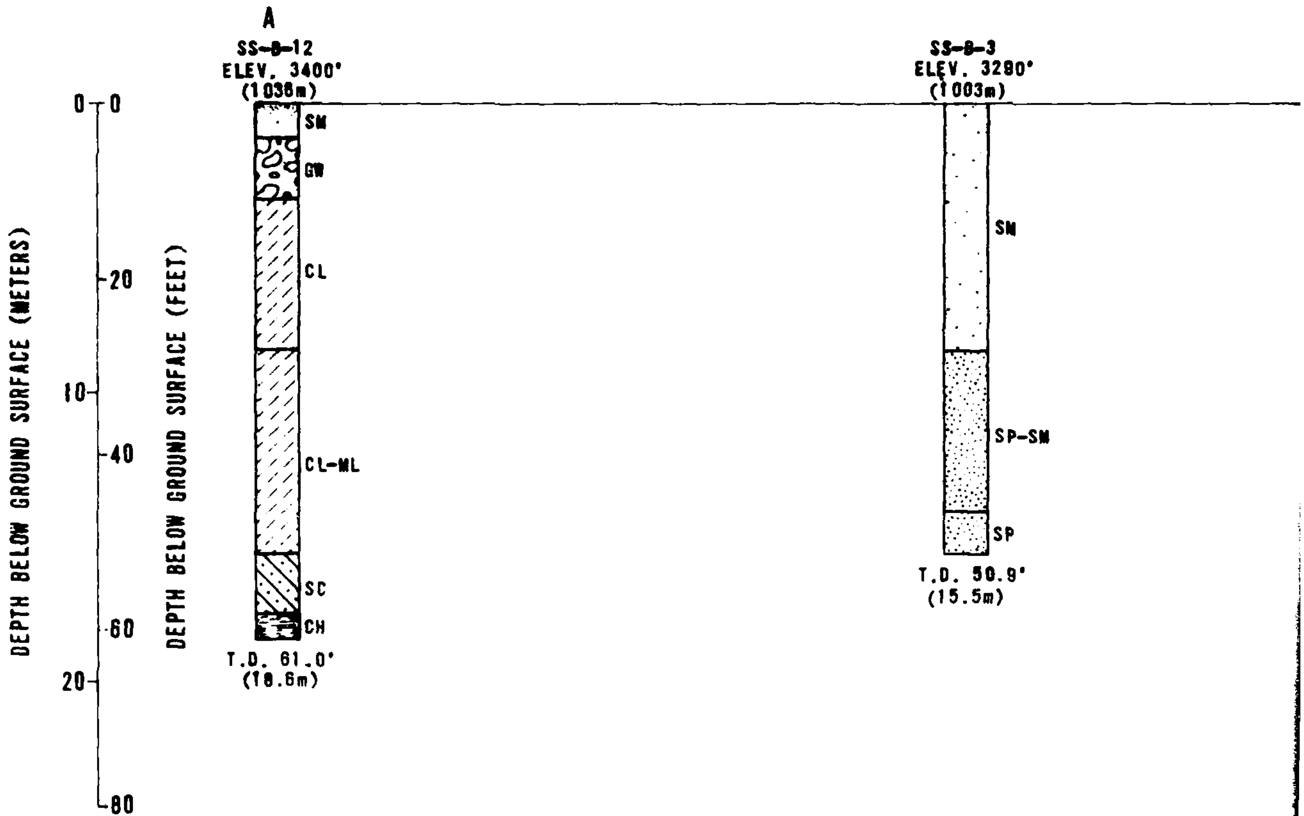
Geophysical investigations indicate shallow rock surfaces only around the valley peripheries. Although no deep seismic or gravity surveys were conducted in San Simon, available data indicate that the top of buried rock is more than 2000 feet (610 m) below the ground surface along the valley axis (Figure 3.6-6).

Ground water generally occurs at depths exceeding 50 feet (15 m) throughout the site. Depths gradually increase from 50 feet (15 m) on the east side of the valley to 200 feet (61 m) in the southwestern corner. This is based on information from numerous wells and regional ground-water resource evaluations.

3.6.3 Engineering and Geophysical Properties

Younger, intermediate and older alluvial fan deposits and older lacustrine deposits are the predominant geologic units of San Simon Valley. Their engineering and geophysical properties are summarized in Table 3.6-3 and Figure 3.6-7.

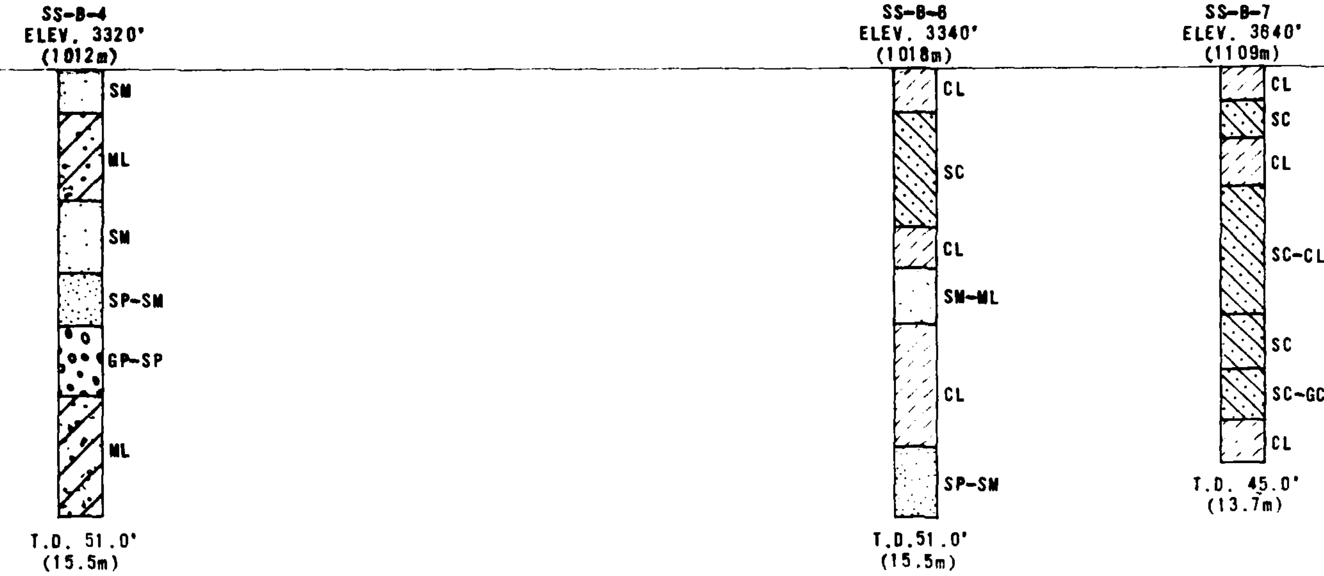
Younger and intermediate alluvial fan units were combined due to their similar grain size and other engineering characteristics. Alluvial fan deposits are generally comprised of clayey and silty sands and gravel which have low compressibility and moderately high shear strengths.



NOTES: 1. Ground surface elevat

2. T.D.=Total Depth

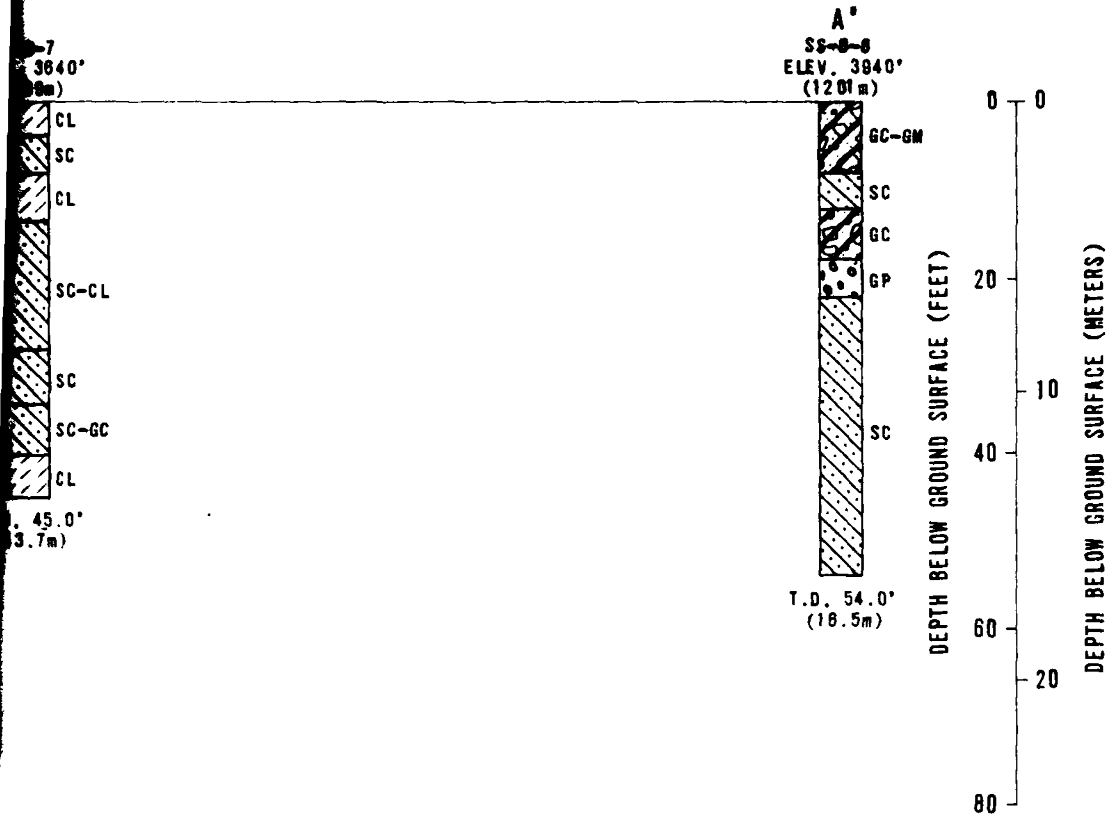
3. Soil types shown adja
(USCS) and are expla



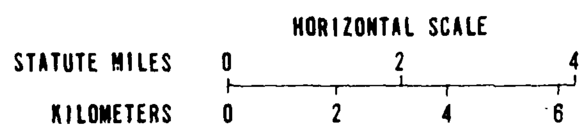
STATU

KI

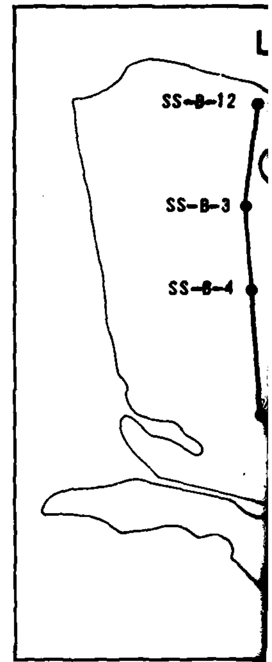
face elevations shown at locations of borings are approximate
l Depth
shown adjacent to soil column are based on Unified Soil Classification System
d are explained in the appendix



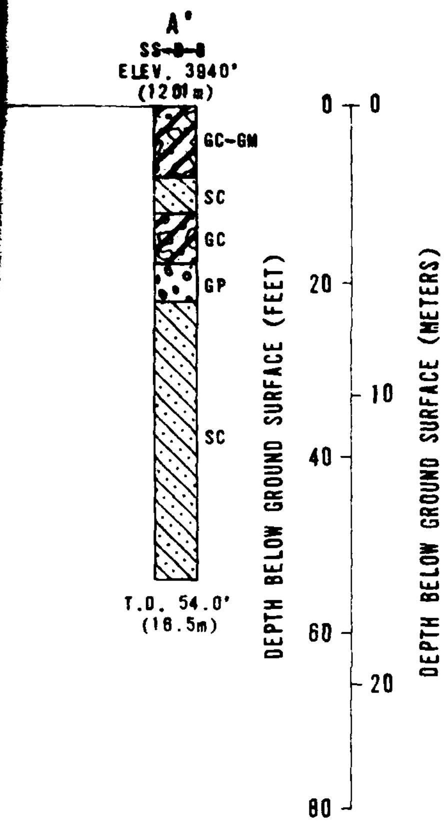
A'
SS-B-8
ELEV. 3940'
(1201m)
GC-GM
SC
GC
GP
SC
T.D. 54.0'
(16.5m)
3640'
CL
SC
CL
SC-CL
SC
SC-GC
CL
45.0'
3.7m)
DEPTH BELOW GROUND SURFACE (FEET)
DEPTH BELOW GROUND SURFACE (METERS)
0
20
40
60
80
0
10
20

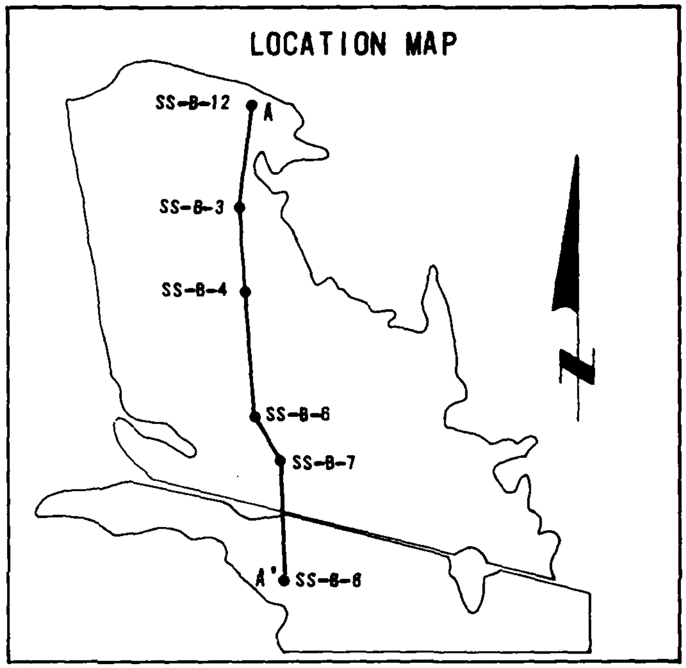


HORIZONTAL SCALE
STATUTE MILES 0 2 4
KILOMETERS 0 2 4 6



SS-B-12
SS-B-3
SS-B-4



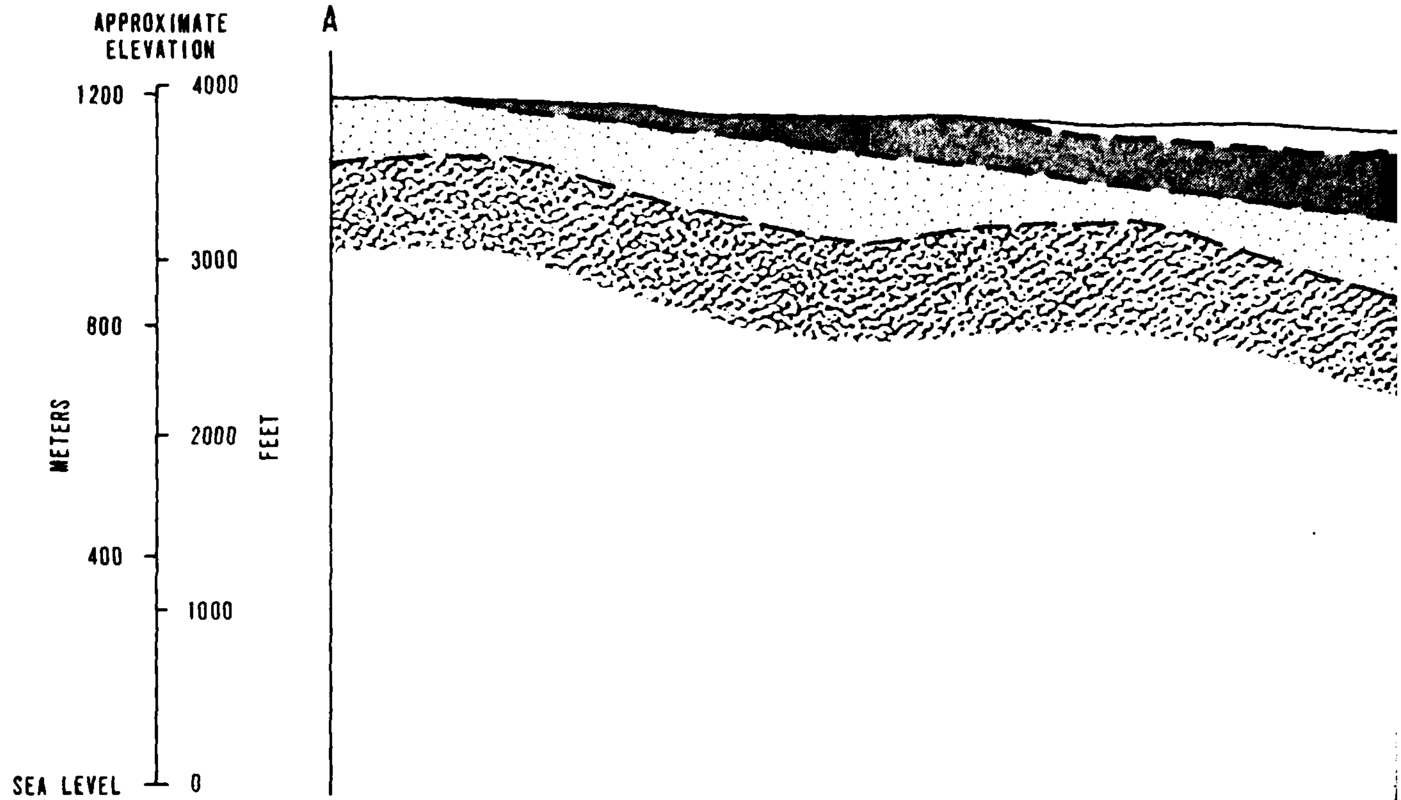


SOIL PROFILE
SAN SIMON, ARIZONA
HIGHLANDS CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE 3.6-5

FUGRO NATIONAL, INC.



EXPLANATION

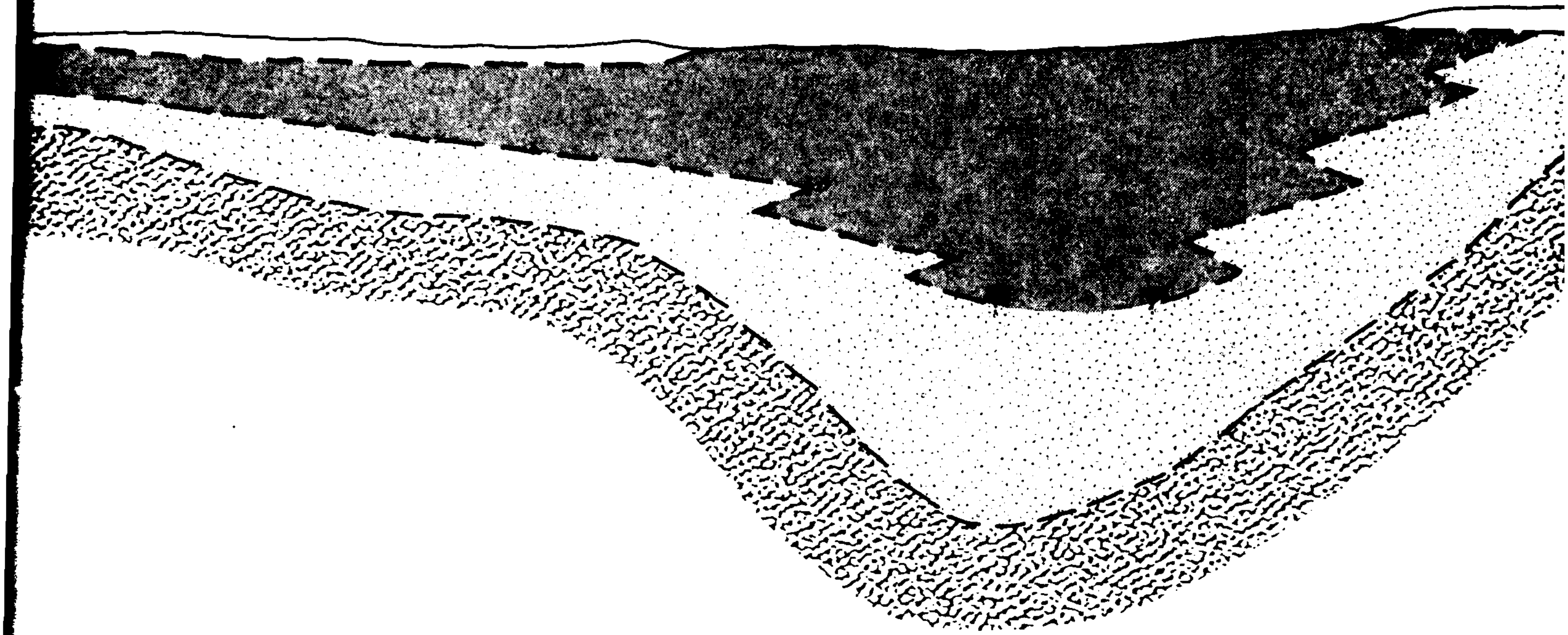
Surficial basin fill; alluvial fan, eolian, and

Older lacustrine deposits

Undifferentiated older basin fill

Rock

Approximate geologic contact



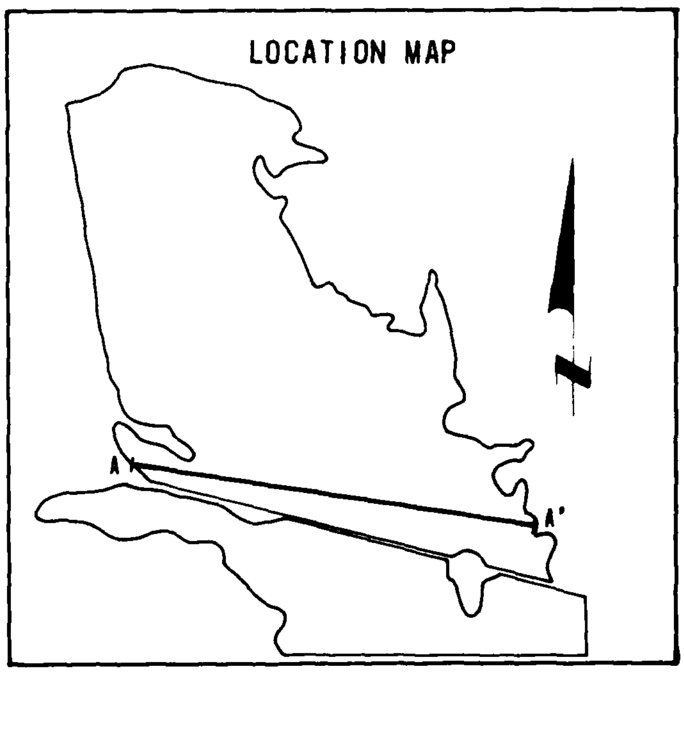
ATION

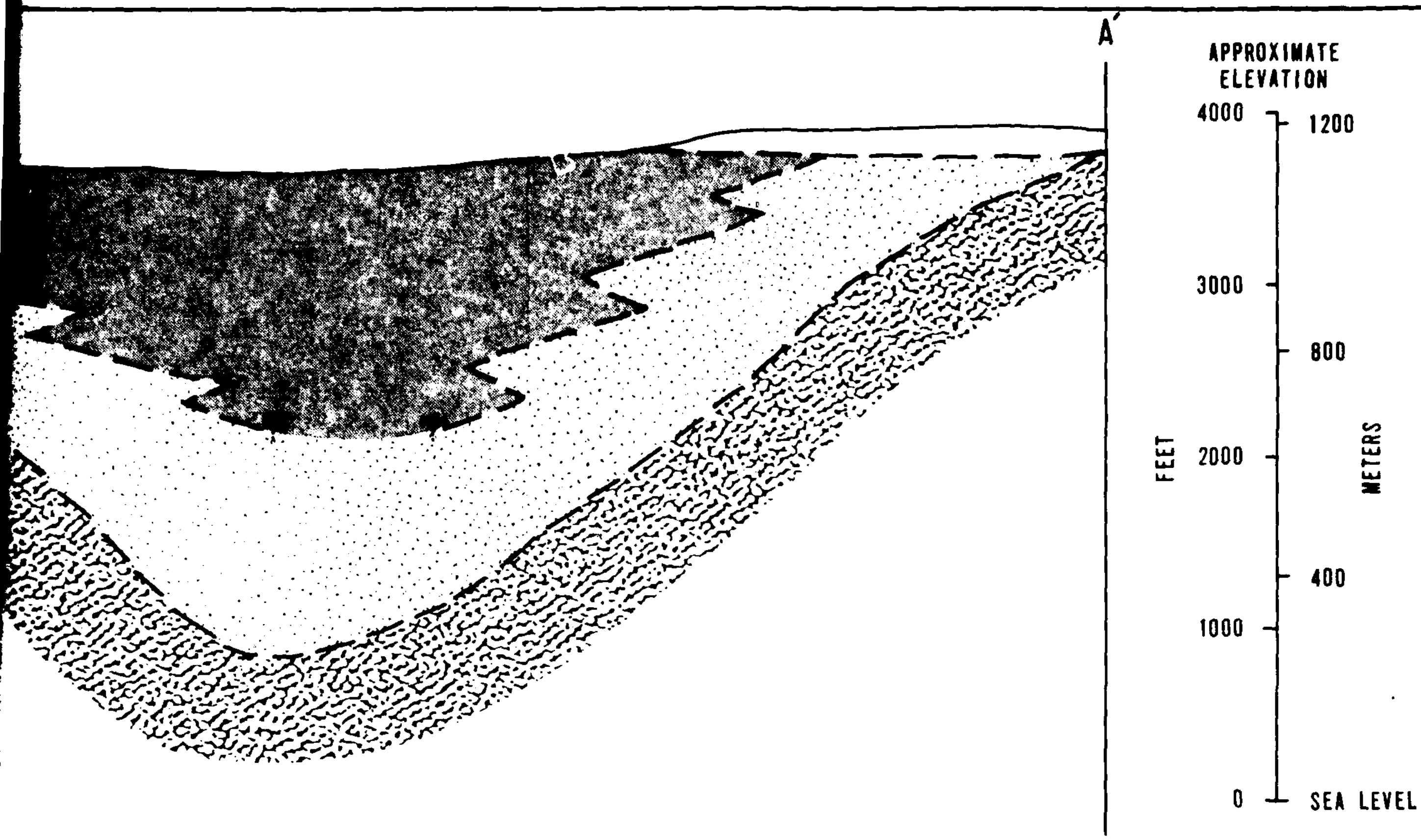
luvial fan, eolian, and fluvial deposits

s

asin fill

ntact





Horizontal Scale: 1" ≈ 2 Miles (3 km)
Vertical Scale: 1" = 1000 Feet (305 m)
Vertical Exaggeration: 10.5x

GENERALIZED GEOLOGIC CROSS SECTION
SAN SIMON VALLEY, ARIZONA
HIGHLANDS CSP

MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE - SAMSO	FIGURE 3.6-6

FUGRO NATIONAL, INC.

ENGINEERING AND GEOPHYSICAL PROPERTIES		
	Younger and intermediate alluvial fan deposits (A5i and A5y)	Older lacustrine
UNIFIED SOIL CLASSIFICATION SYMBOL(S)	SM, SC, GM, GC, GP, CL	CL, CH,
GENERAL PROPERTIES		
DRY DENSITY pcf(kg m^3)	90-122 (1442-1954)	85-117 (
MOISTURE CONTENT (%)	2-28	2-3
DEGREE OF SATURATION (%)	25-85	14-
SPECIFIC GRAVITY	2.63-2.70	2.63-
DEGREE OF CEMENTATION	None to moderate	Weak to
COMPRESSIONAL WAVE VELOCITIES fps(mps)	1000-4680 (305-1426)	1050-2920
ELECTRICAL CONDUCTIVITY (mhos m)	DNA	.005 -
GRAIN SIZE DISTRIBUTION (%)		
BOULDERS >12 inches(30cm)	0-10	0
COBBLES 3 to 12 inches(8to 30cm)	0-25	0-5
GRAVEL	0-55	0-2
SAND	0-90	0-
SILT AND CLAY	10-97	0-
PLASTICITY DATA		
LIQUID LIMIT	19-72	26-
PLASTICITY INDEX	NP-44	NP-
COMPRESSIBILITY DATA		
COMPRESSION AT 4 ksf(192kN/m^2) (%)	0.8-2.3	0.5-
SWELL OR COLLAPSE UPON SATURATION (%)	0.2-1.4(Swell)	0.3-
SHEAR STRENGTH DATA		
UNCONFINED COMPRESSION ksf(kN/m^2)	2.0-6.9 (96-330)	3.6-34.4 (
CD TRIAXIAL COMPRESSION	DNA	c =1-3 ksf(48-144 k
DIRECT SHEAR ksf(kN/m^2)	0.4-5.7 (19-273)	0.4-3.7
COMPACTION AND CBR DATA		
MAXIMUM DRY DENSITY pcf(kg m^3)	118-135 (1898-2162)	115-126 (1
OPTIMUM MOISTURE CONTENT (%)	9.8-12.5	10.5-
CBR AT 90% RELATIVE COMPACTION	20-30	6-

DNA=DATA NOT AVAILABLE (INSUFFICIENT DATA OR TESTS NOT PERFORMED)

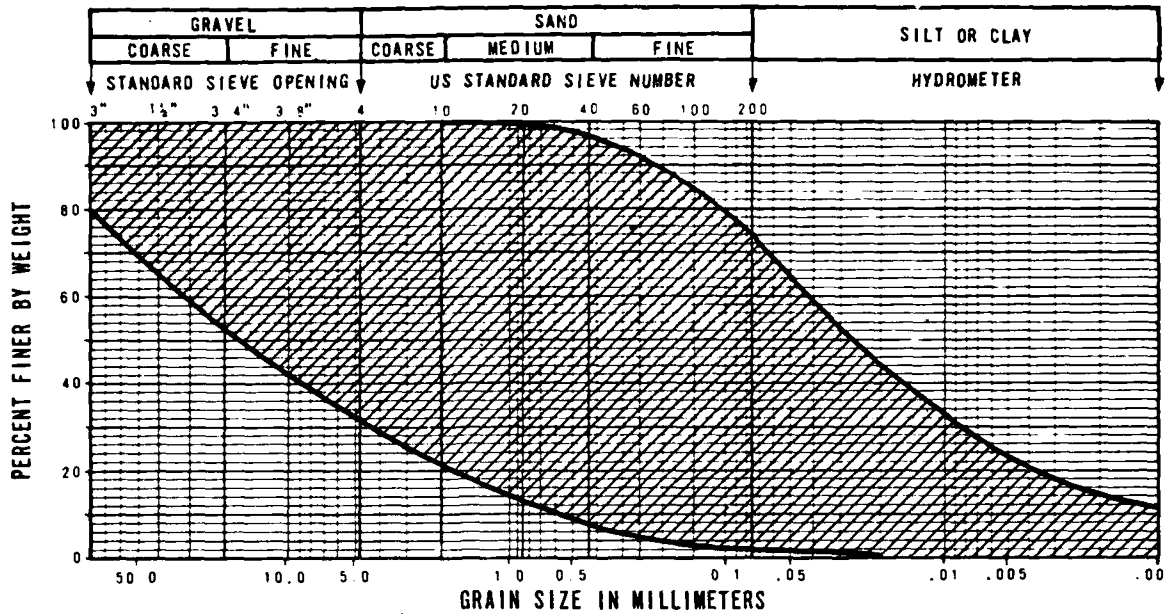
GEOLOGIC UNITS	
r lacustrine deposits (A4o)	
CL. CH. ML. SW. SP	
85-117 (1362-1874)	
2-30	
14-90	
2 63-2 68	
Weak to strong	
1050-2920 (320-890)	
.005 - .191	
0	
0-5	
0-20	
0-88	
0-98	
26-84	
NP-60	
0.5-1 6	
0.3-1 2 (Swell)	
3 6-34.4 (172-1647)	
ksf(48-144 kN m 2), ϕ = 12°-25°	
0.4-3.7 (19-177)	
115-126 (1842-2018)	
10.5-15.8	
6-9	

RANGE OF ENGINEERING AND GEOPHYSICAL PROPERTIES
SAN SIMON VALLEY, ARIZONA

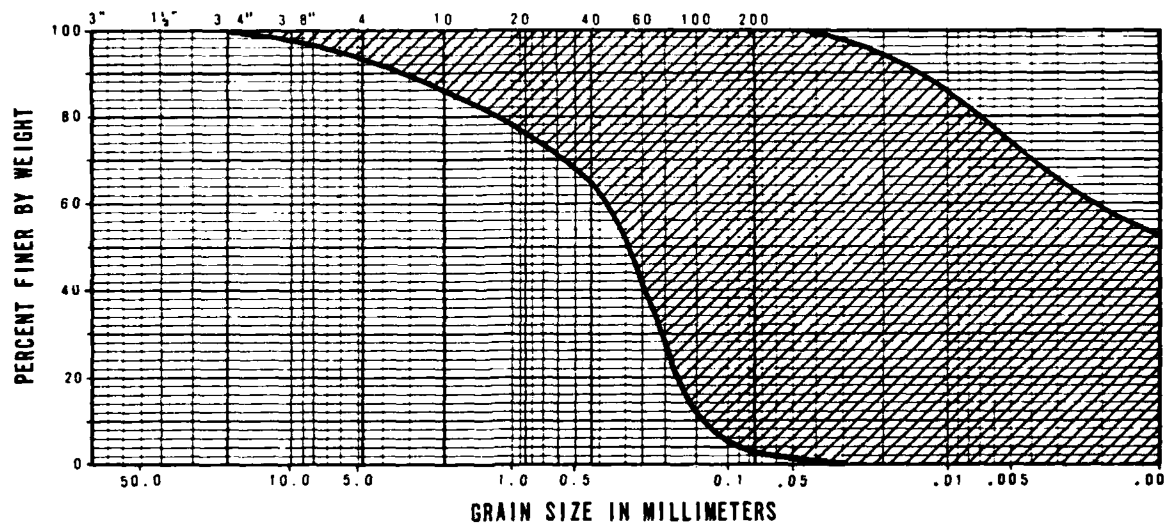
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

TABLE 3.6-3

FUGRO NATIONAL, INC.



A5



A4o

RANGE OF GRADATION OF GEOLOGIC UNITS
SAN SIMON VALLEY, ARIZONA
HIGHLANDS CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.6-7

FUGRO NATIONAL, INC.

Older lacustrine deposits are primarily encountered in the northern and northeastern portions of the valley and are generally comprised of clay and silt. The unit has generally low compressibility and high shear strength and may have some expansion potential upon exposure to water.

3.6.4 Conclusions

The following favorable and unfavorable geotechnical conditions for deployment of the MX system in San Simon Valley are based on the results of the Characterization study.

Favorable conditions:

- Except near the mountains and in the northeastern portion of the site, slopes are typically less than one percent requiring little preconstruction grading.
- Drainage incisions are generally less than six feet (2 m) deep, therefore, major drainage structures will not be required.
- Surficial soils have good to excellent support characteristics as subgrade for roads.
- Soils are generally suitable for excavation of vertical shelters using an auger, continuous trenches using an MX trencher, and horizontal shelters using conventional excavation methods.

- o Sufficient quantities of aggregate and water required for roads and concrete are available within and/or adjacent to the site area.
- o Depth to rock over most of the site is expected to be greater than 150 feet (46 m).
- o Depth to ground water is greater than 50 feet (15 m) throughout the site and generally ranges from 50 to 200 feet (15 to 61 m).
- o Land is administered by BLM.

Unfavorable conditions:

- o In the northeast, approximately 20 percent of the valley is highly dissected and drainage incisions of greater than ten feet (3 m) deep are common requiring major drainage structures.
- o No regular network of paved or unpaved roads exists and construction of new roads will be required.
- o Existing wells are insufficient to provide the water needed for construction and additional wells will be required.

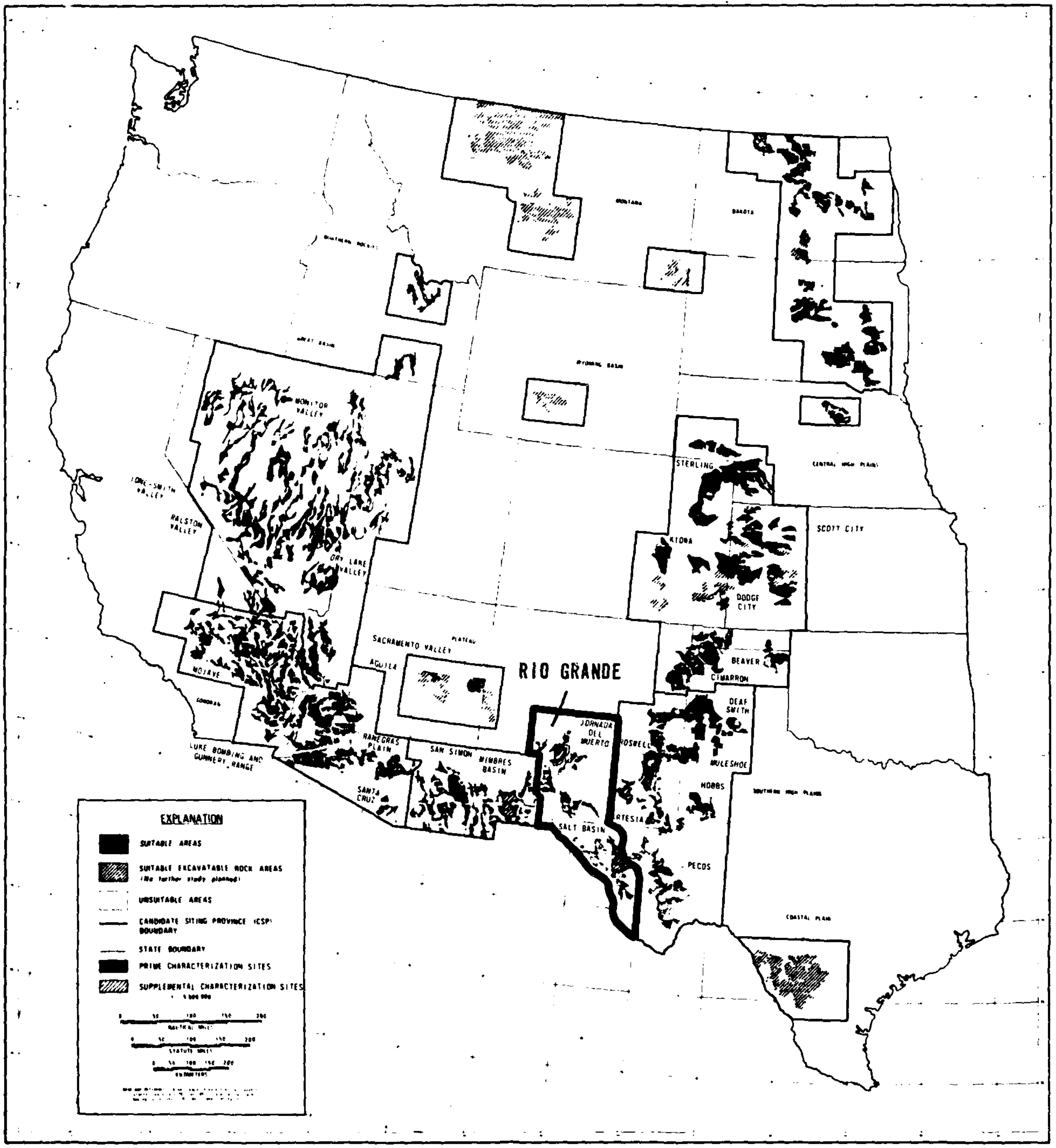
In summary, the San Simon characterization site presents favorable geotechnical conditions for deployment of the present MX basing mode concepts.

3.7 JORNADA DEL MUERTO: RIO GRANDE CSP

The Rio Grande CSP lies within the Mexican Highlands and Sacramento sections of the Basin and Range physiographic province and covers portions of New Mexico and Texas (Figure 3.7-1). Approximately 50 percent of the CSP is privately owned. Federal and state agencies control 42 and eight percent of the remaining area, respectively. The estimated land use within the CSP is 99 percent rangeland and one percent irrigated farmland.

The CSP is characterized by predominantly north and northwest trending mountain ranges, separated by fault controlled, closed basins possessing a variety of geologic and engineering conditions. Two sites were selected to characterize geotechnical conditions within the CSP (Figure 3.7-2) based upon a review of regional geologic and engineering literature. Results of the Jornada del Muerto investigation are presented to provide a sampling of geotechnical conditions encountered within the Rio Grande CSP.

The Jornada del Muerto site covers an area of 330 nm^2 (1132 km^2) and is situated entirely within the White Sands Missile Range, Socorro and Sierra Counties, New Mexico. The site occupies a portion of a broad alluvial basin interjacent to the San Andres and Oscura Mountains to the east and the Rio Grande River to the west. Field activities for the Characterization study are identified in Figure 3.7-3. The scope of both the field and laboratory activities is presented in Table 3.7-1.

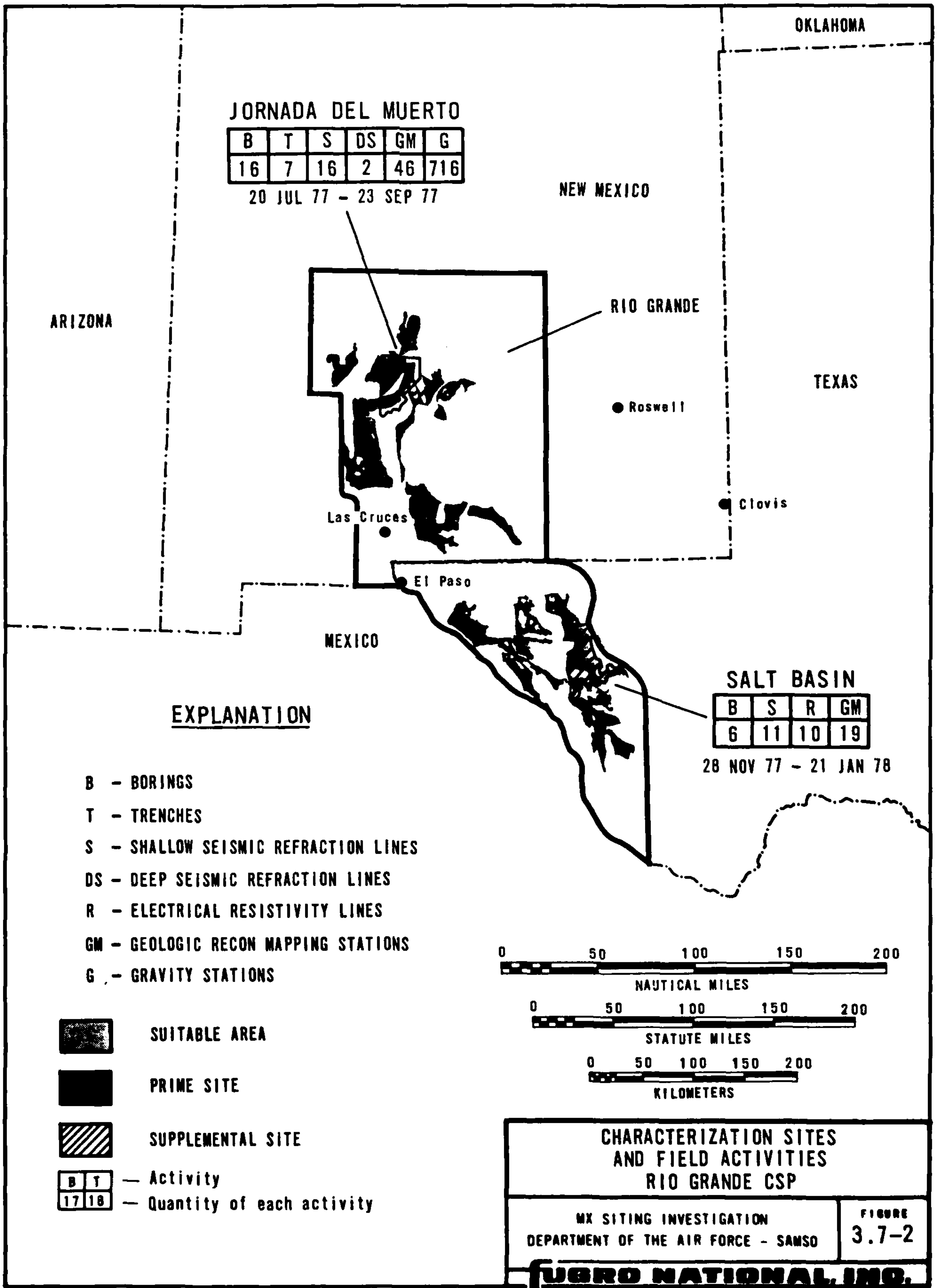


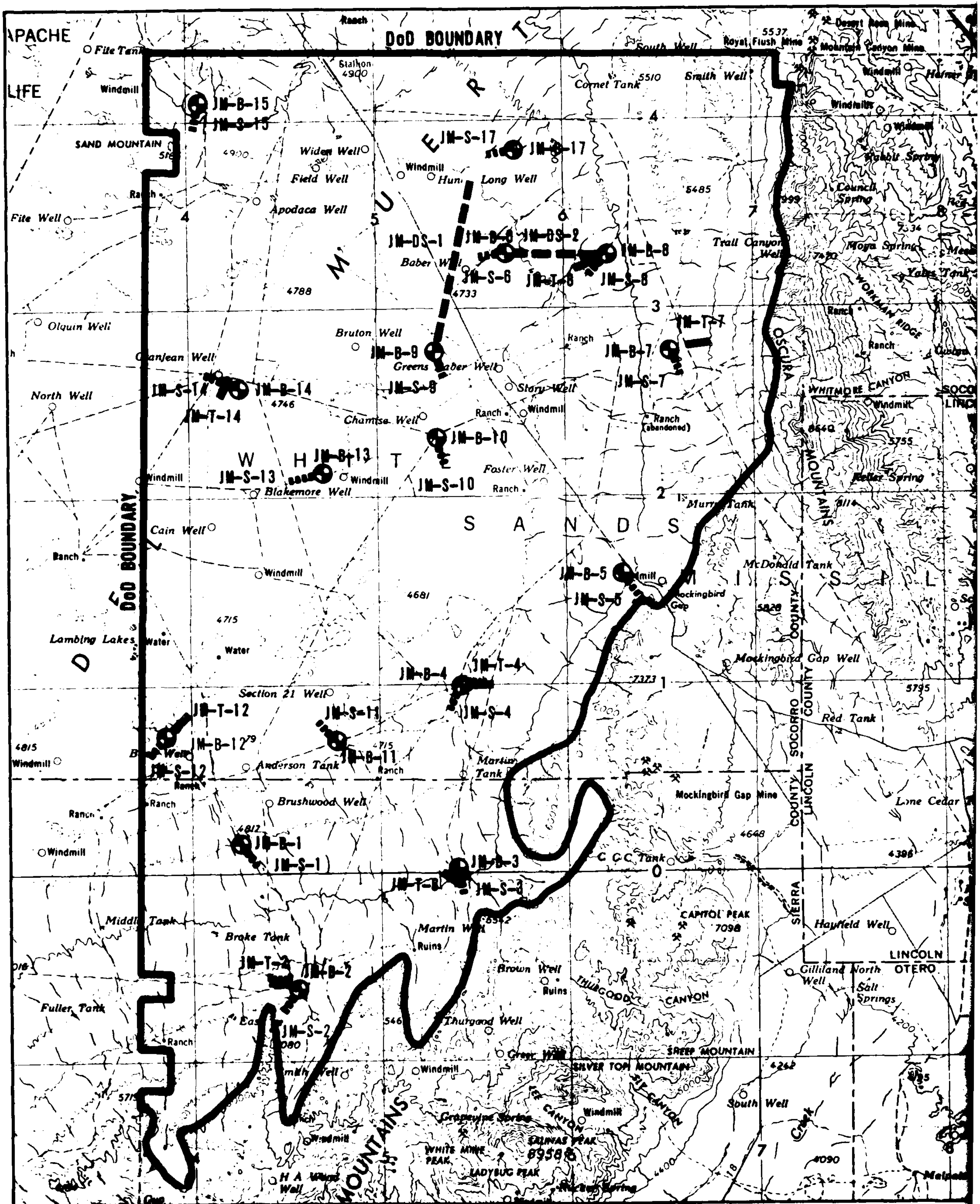
LOCATION OF RIO GRANDE CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

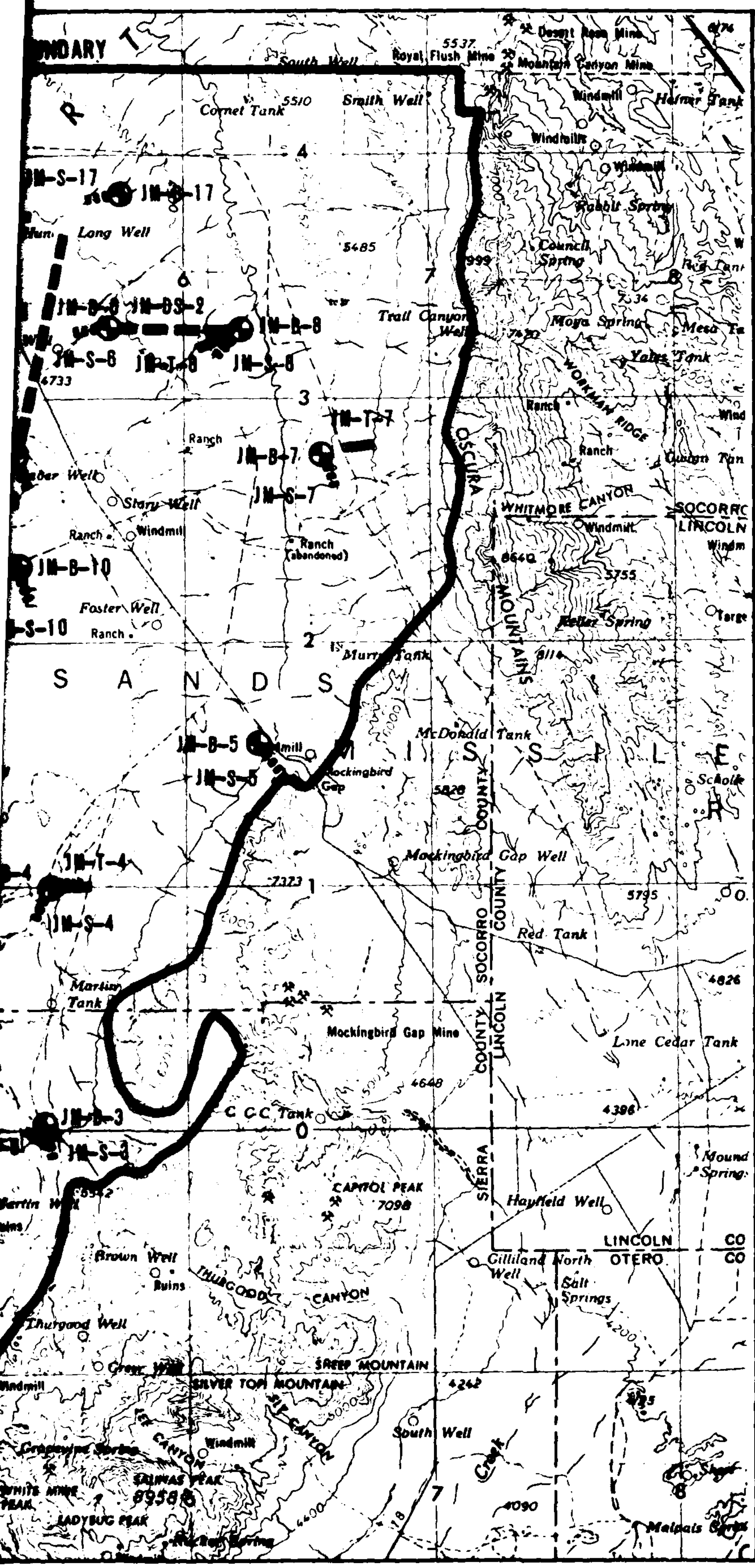
FIGURE 3.7-1

FUGRO NATIONAL, INC.


OKLAHOMA
JORNADA DEL MUERTO
B T S DS GM G
16 7 16 2 46 716
20 JUL 77 - 23 SEP 77
NEW MEXICO
ARIZONA
RIO GRANDE
TEXAS
Roswell
Clovis
Las Cruces
El Paso
MEXICO
SALT BASIN
B S R GM
6 11 10 19
28 NOV 77 - 21 JAN 78
EXPLANATION
B - BORINGS
T - TRENCHES
S - SHALLOW SEISMIC REFRACTION LINES
DS - DEEP SEISMIC REFRACTION LINES
R - ELECTRICAL RESISTIVITY LINES
GM - GEOLOGIC RECON MAPPING STATIONS
G - GRAVITY STATIONS
SUITABLE AREA
PRIME SITE
SUPPLEMENTAL SITE
B T — Activity
17 18 — Quantity of each activity
0 50 100 150 200
NAUTICAL MILES
0 50 100 150 200
STATUTE MILES
0 50 100 150 200
KILOMETERS
CHARACTERIZATION SITES
AND FIELD ACTIVITIES
RIO GRANDE CSP
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO
FIGURE
3.7-2
FUGRO NATIONAL, INC.



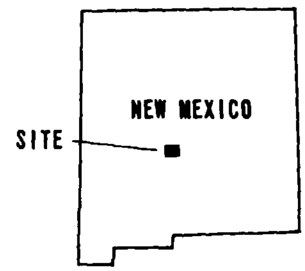
DoD BOUNDARY
APACHE
LIFE
Fite Tank
Windmill
SAND MOUNTAIN
Fite Well
Widen Well
Field Well
Apodaca Well
Long Well
Cornet Tank
Smith Well
South Well
Royal Flush Mine
Trail Canyon Well
Baber Well
Olguin Well
Bruton Well
Greens Baber Well
North Well
Chamise Well
Foster Well
Blakemore Well
Cain Well
Lambing Lakes
Water
Section 21 Well
Anderson Tank
Brushwood Well
Martin Tank
Mockingbird Gap Mine
Mockingbird Gap
Mockingbird Gap Well
McDonald Tank
Red Tank
Lone Cedar
C C C Tank
CAPITOL PEAK
7098
Hayfield Well
Middle Tank
Broke Tank
Martin Well
Ruins
Brown Well
THURGOOD CANYON
Thurgood Well
Fuller Tank
SHEEP MOUNTAIN
SILVER TOP MOUNTAIN
Gilliland North Well
Salt Springs
LINCOLN
OTERO
SOCORRO COUNTY
LINCOLN COUNTY
SIERRA COUNTY
South Well
LADYBUG PEAK
WHITE MINE PEAK
SALINAS PEAK
8958
MOUNTAINS
H A Wood Well
OSCURA MOUNTAINS
WORKMAN RIDGE
WHITMORE CANYON
Council Spring
Moya Spring
Yates Tank
Rabbit Spring
W H I T E S A N D S M I S S I L E
JM-B-15
JM-S-15
JM-S-17
JM-B-17
JM-DS-1
JM-DS-2
JM-B-6
JM-S-6
JM-T-6
JM-B-8
JM-S-8
JM-T-7
JM-B-7
JM-S-7
JM-B-9
JM-S-9
JM-S-14
JM-B-14
JM-T-14
JM-B-10
JM-S-10
JM-B-13
JM-S-13
JM-B-5
JM-S-5
JM-B-4
JM-T-4
JM-S-4
JM-T-12
JM-B-12
JM-S-12
JM-S-11
JM-B-11
JM-B-1
JM-S-1
JM-B-3
JM-T-3
JM-S-3
JM-T-2
JM-B-2
JM-S-2



EXPLANATION

- Boring
- Deep seismic refraction line
- Seismic refraction line
- Trench

SITE LOCATION



1:250,000

1" = 3.2 Nautical Miles
(APPROXIMATE)

ACTIVITY LOCATION MAP
JORNADA DEL MUERTO, NEW MEXICO
RIO GRANDE CSP

MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE - SAMSO	FIGURE 3.7-3

FUGRO NATIONAL, INC.

GEOLOGY AND GEOPHYSICS

TYPE OF ACTIVITY	NUMBER OF ACTIVITIES
Geological mapping stations	46
Shallow refraction	16
Deep refraction	2
Downhole velocity	3
Gravity survey	716

ENGINEERING

NUMBER OF BORINGS	DEPTH FEET(METERS)
13	100 (30)
3	300 (91)
NUMBER OF TRENCHES	DEPTH FEET(METERS)
1	16 (5)
6	18 (6)

ENGINEERING-LABORATORY TESTS

TYPE OF TEST	NUMBER OF TESTS
Moisture/density	237
Specific gravity	19
Sieve analysis	130
Hydrometer	53
Atterberg limits	90
Consolidation	10

TYPE OF TEST	NUMBER OF TESTS
Unconfined compression	29
Triaxial compression	18
Direct shear	30
Compaction	7
CBR	4
Chemical analysis	8

SCOPE OF FIELD AND LABORATORY ACTIVITIES
JORNADA DEL MUERTO, NEW MEXICO

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

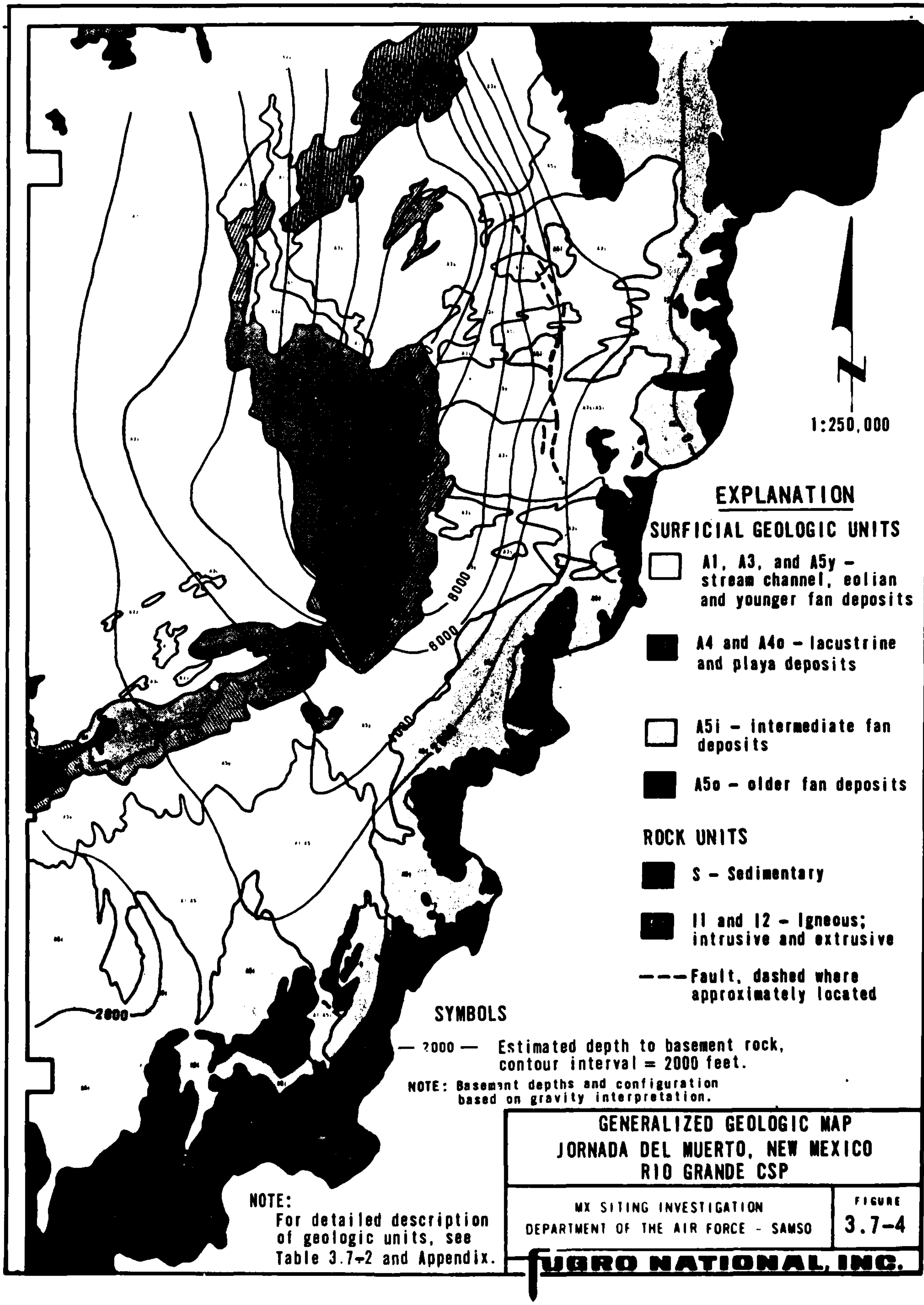
TABLE 3.7-1

FUGRO NATIONAL, INC.

3.7.1 Surficial Geology and Terrain

Eolian sheet sand deposits are the dominant surficial geologic materials covering over 45 percent of the Jornada del Muerto site (Figure 3.7-4), and they commonly veneer older basin-fill materials at depths ranging from less than one foot (0.3 m) to greater than 18 feet (5.5 m). Intermediate and younger alluvial fan deposits have been delineated over 22 and 14 percent of the site, respectively. While the sheet sands are predominantly sand or silty sand, the alluvial fan deposits vary from clayey silt and silty sand near the basin axis to silty sand with gravel and cobbles near the mountain fronts. Older lacustrine deposits comprised of clay, silt, and sand are exposed over only nine percent of the surface area, but they underlie most of the other surficial geologic deposits. These four units along with the remaining units are described in Table 3.7-2.

Surface slopes and depths of drainage incision vary with geologic units, but generally are higher nearer the mountain fronts (Table 3.7-2). Maximum surface slope (again excluding older alluvial fan deposits) is nine percent with typical slopes less than two percent. Maximum depths of incision (excluding older alluvial fan deposits) are 25 feet (7.6 m) with typical depths less than five feet (1.5 m).


1:250,000
EXPLANATION
SURFICIAL GEOLOGIC UNITS
A1, A3, and A5y - stream channel, eolian and younger fan deposits
A4 and A4o - lacustrine and playa deposits
A5i - intermediate fan deposits
A5o - older fan deposits
ROCK UNITS
S - Sedimentary
I1 and I2 - Igneous; intrusive and extrusive
Fault, dashed where approximately located
SYMBOLS
2000 — Estimated depth to basement rock, contour interval = 2000 feet.
NOTE: Basement depths and configuration based on gravity interpretation.
NOTE: For detailed description of geologic units, see Table 3.7-2 and Appendix.
8000
2000
GENERALIZED GEOLOGIC MAP
JORNADA DEL MUERTO, NEW MEXICO
RIO GRANDE CSP
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO
FIGURE 3.7-4
FUGRO NATIONAL, INC.

ENGINEERING GEOLOGY UNIT (d)	GEOLOGIC AGE	THICKNESS FEET (METERS)	DESCRIPTIVE NAME(S)	USCS SYMBOL(S)	AREAL EXTENT	
					nm^2 (km^2)	P
Fluvial Deposits (A1)	Quaternary	Unknown	Silty Sand with Clay	SM	20 (69)	
Eolian Deposits Sheet and Dune Sand (A3s, A3d)	Quaternary	0-18 (0-6)	Sand, Silty Sand, Silty Sand with Clay	SP, SM	149 (511)	
Playa Deposits (A4)	Quaternary	Unknown	Silt and Clay	ML, CL	10 (34)	
Older Lacustrine and Playa Deposits (A4o)	Quaternary-Tertiary	Unknown	Clay, Gypsiferous Silt, Silty Sand	CL, ML, SM	30 (103)	
Younger Alluvial Fan Deposits (A5y)	Quaternary	Unknown	Silty and Clayey Sand with Gravel, Silt, Clay	SM, SC	46 (158)	
Intermediate Alluvial Fan Deposits (A5i)	Quaternary	Unknown	Silty Sand with Gravel and Cobbles	SM	73 (250)	
Older Alluvial Fan Deposits (A5o)	Quaternary-Tertiary	Unknown	Sandy Gravel with Cobbles and Boulders	SP-GW	3 (10)	

NOTES:

(a) Mixed with A5i deposits in the southern part of the site; designated A1 A5y on Figure 3.7-4.

(b) Dune sands comprise one percent of the site area.

(c) This gypsiferous deposit occurs extensively in the subsurface.

(d) For generic description of geologic units, see Appendix.

(S)	AREAL EXTENT (SITE)		PROPERTIES OF SURFACE MATERIALS					SURFACE MORPHOLOGY		NOTES
	nm^2 (km^2)	PERCENT	GRADATION	CEMENTATION	MAXIMUM GRAIN SIZE	PAVEMENT/ PATINA	STAGE OF CALICHE	SLOPE (PERCENT)	DRAINAGE DEPTHS FEET(METERS)	
	20 (69)	6	Well	None-Moderate	Sand	None/None	I	< 1	None	(a)
	149 (511)	45	Poor-Moderately well	None-Weak	Sand	None/None	I	< 1	< 1	(b)
L	10 (34)	3	Poor	None-Weak	Silt	None/None	None	< 1	None	
SM	30 (103)	9	Poor	Weak-Strong	Sand	None/None	None-II	< 1	0-5 (0-2)	(c)
C	46 (158)	14	Moderately well	None-Weak	Sand	None/None	I	1-4	<1-6 (<1-2)	
	73 (250)	22	Moderately well-Well	Moderate-Strong	Cobble	Poor/Poor	II	2-9	5-25 (2-8)	
W	3 (10)	1	Moderately well	Moderate-Strong	Boulder	None/None	II-III	9-12	50-100 (16-33)	

DESCRIPTION OF SURFICIAL GEOLOGIC UNITS
JORNADA DEL MUERTO, NEW MEXICO

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

TABLE 3.7-2

FUGRO NATIONAL, INC.

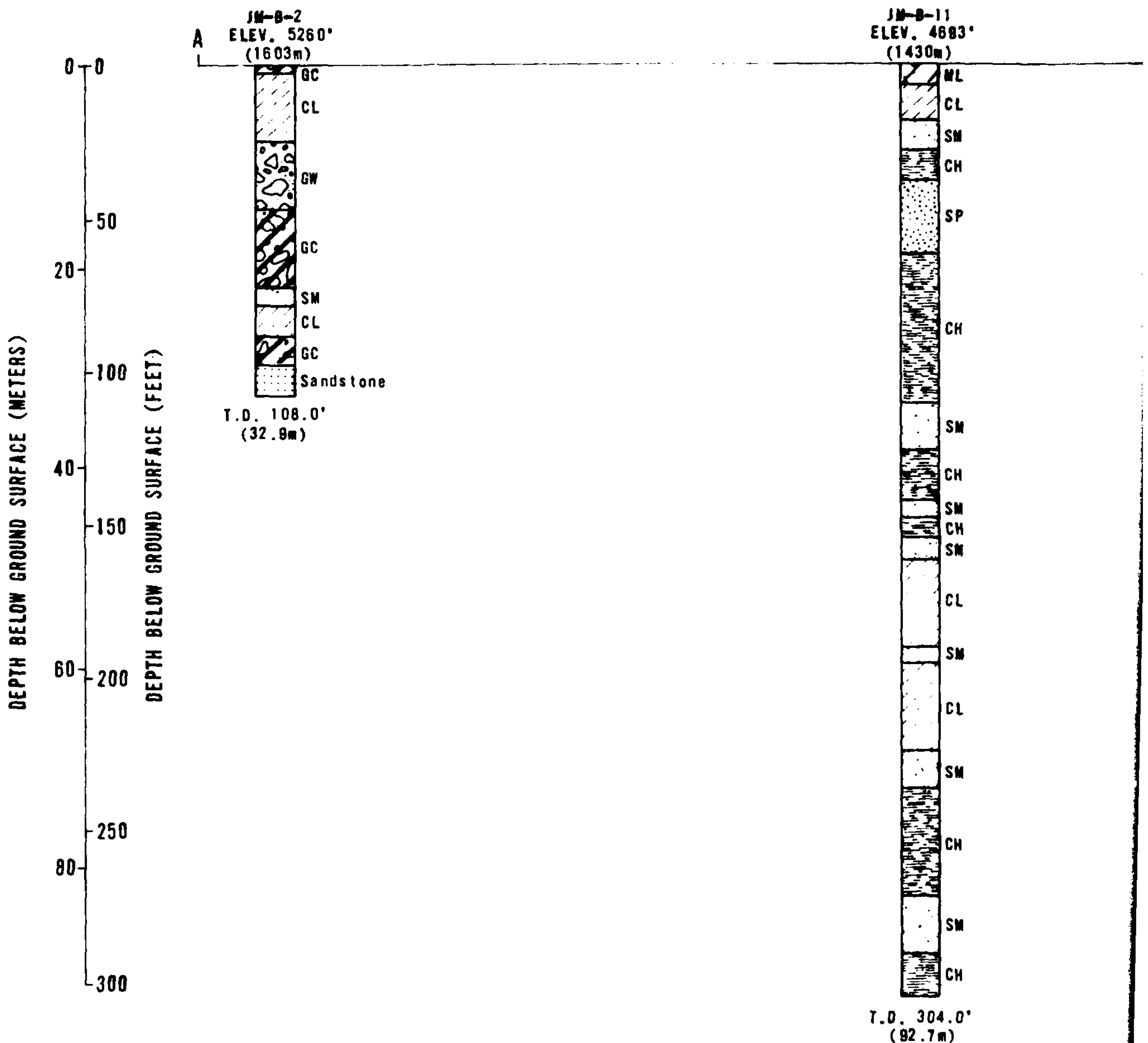
3.7.2 Subsurface Conditions

Varying thicknesses of eolian sheet sand and alluvial fan deposits typically overlie several hundred feet of older lacustrine deposits at Jornada del Muerto. The subsurface conditions and the composition of the soils with depth are illustrated by the soil profile shown in Figure 3.7-5.

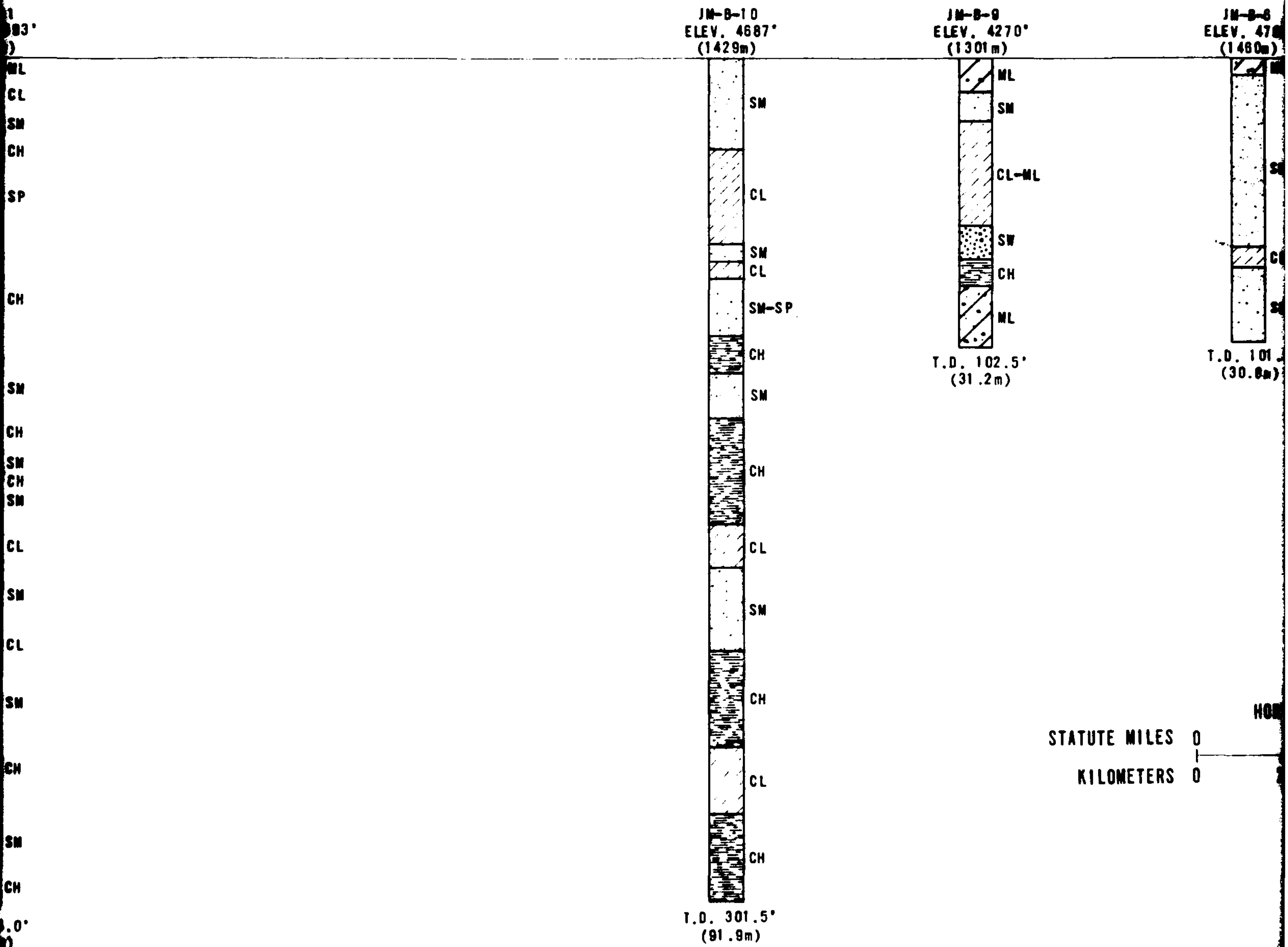
Geophysical investigations indicate bedrock within 50 feet (15 m) of the surface near the mountains in the southern part of the site. Deep seismic lines near the middle of the valley encountered high velocity materials, probably well indurated alluvium, at a depth of 450 feet (140 m).

Gravity data indicate the basement topography of the site is dominated by a 16,000-foot (4900 m) deep basin that is bounded on the east by a steep fault and on the west by a gently sloping plane in the vicinity of the generalized geologic cross-section (Figure 3.7-6). Near the south end of the site, an east-west trending basement ridge separates the large basin from a smaller one. Buried basalt from the Jornada Malpais basalt field overlies much of this ridge. The subsurface basin configuration is illustrated in Figures 3.7-4 and 3.7-6.

The majority of the valley has ground-water depths exceeding 100 feet (30 m). Ground water occurs at depths of 50 feet (15 m) or less in the southeastern portion of the valley and increases to greater than 200 feet (61 m) towards the north-western boundary. This is based on information from several wells and regional ground-water resource evaluations.



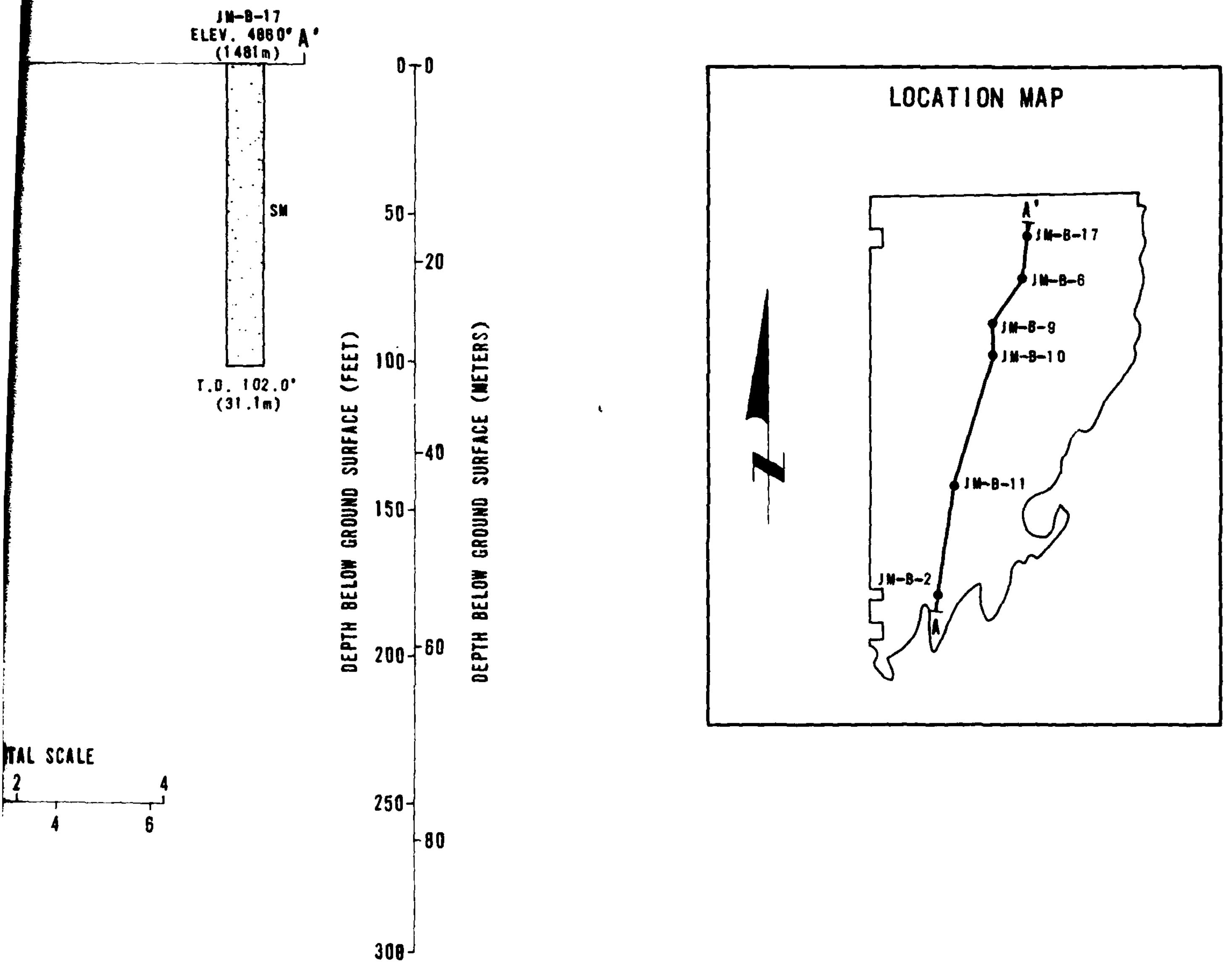
A
JM-B-2
ELEV. 5260'
(1603m)
GC
CL
GW
GC
SM
CL
GC
Sandstone
T.D. 108.0'
(32.9m)
JM-B-11
ELEV. 4693'
(1430m)
ML
CL
SM
CH
SP
CH
SM
CH
SM
CH
SM
CL
SM
CL
SM
CH
SM
CH
T.D. 304.0'
(92.7m)
DEPTH BELOW GROUND SURFACE (METERS)
DEPTH BELOW GROUND SURFACE (FEET)
0
20
40
60
80
0
50
100
150
200
250
300



NOTES: 1. Ground surface elevations shown at locati

2. T.D.=Total Depth

3. Soil types shown adjacent to soil column a (USCS) and are explained in the appendix



borings are approximate

sed on Unified Soil Classification System

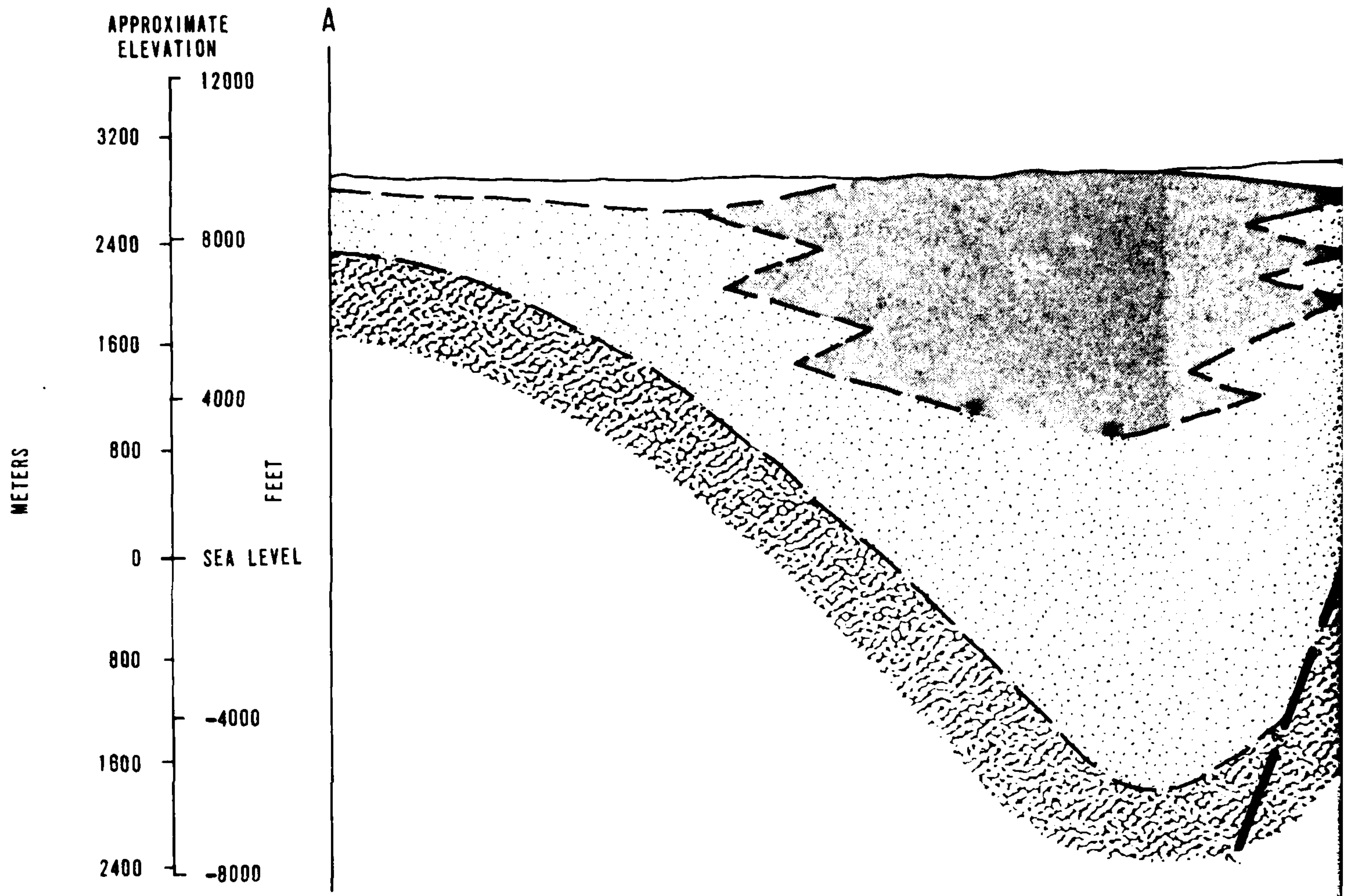
SOIL PROFILE
JORNADA DEL MUERTO, NEW MEXICO
RIO GRANDE CSP

MX SI'ING INVESTIGATION
DEPARTMENT OF THE AIR FORCE · SAMSO

FIGURE 3.7-5

FUGRO NATIONAL, INC.

3



EXPLANATION

Surficial basin fill; alluvial fans, eolian, playa, and fluvial deposits

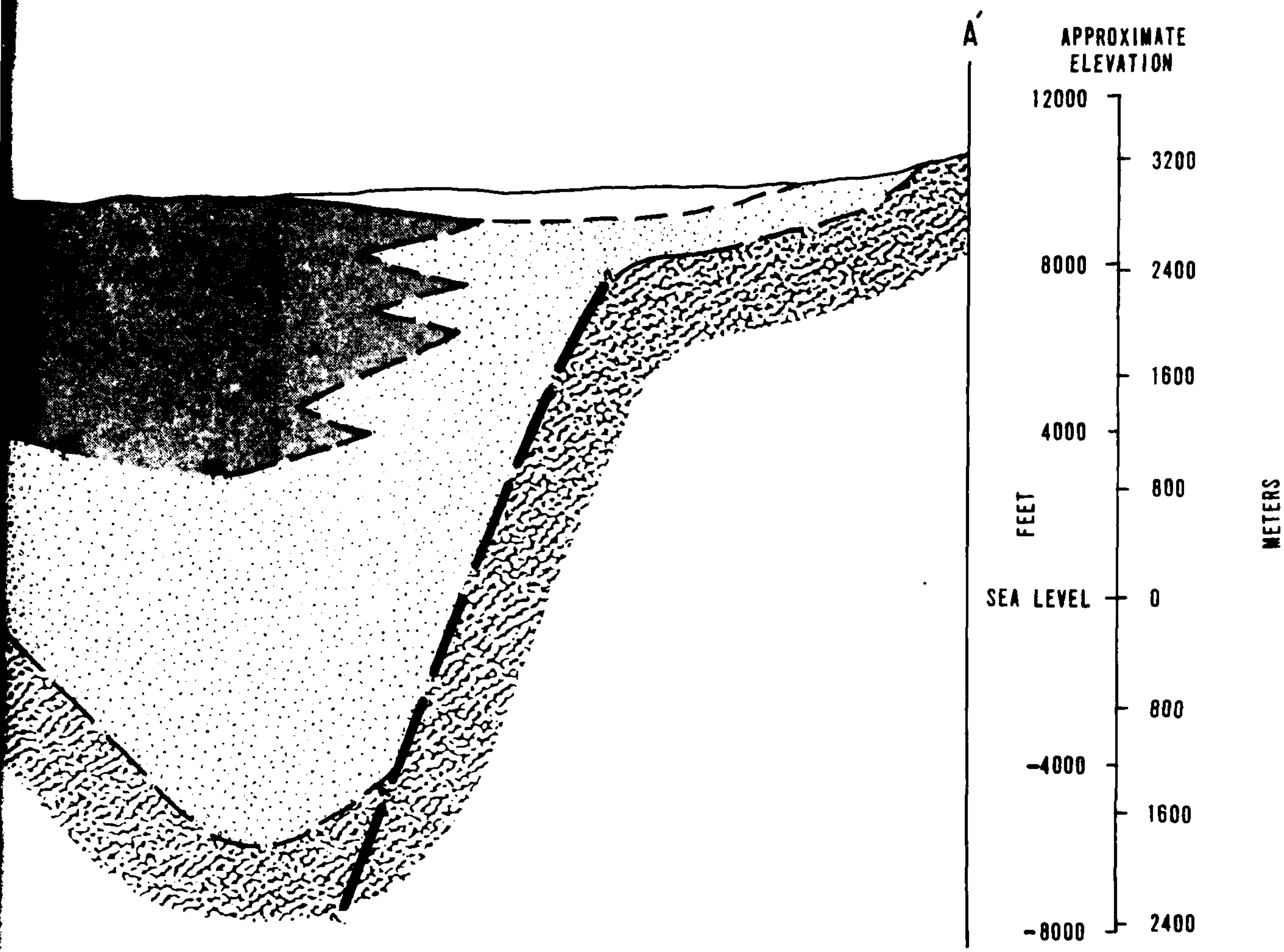
Older lacustrine and playa deposits

Undifferentiated older basin fill

Precambrian metamorphosed rocks

Approximate geologic contact

Fault; geologic/geophysical interpretation

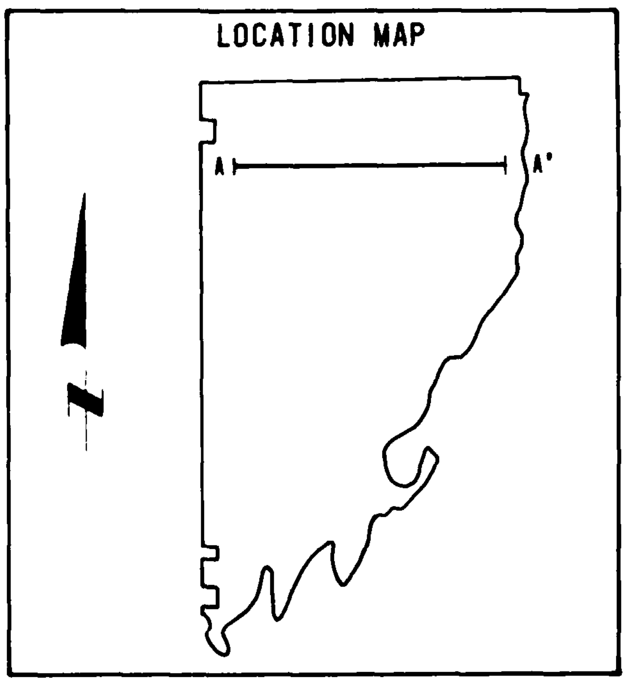


ON

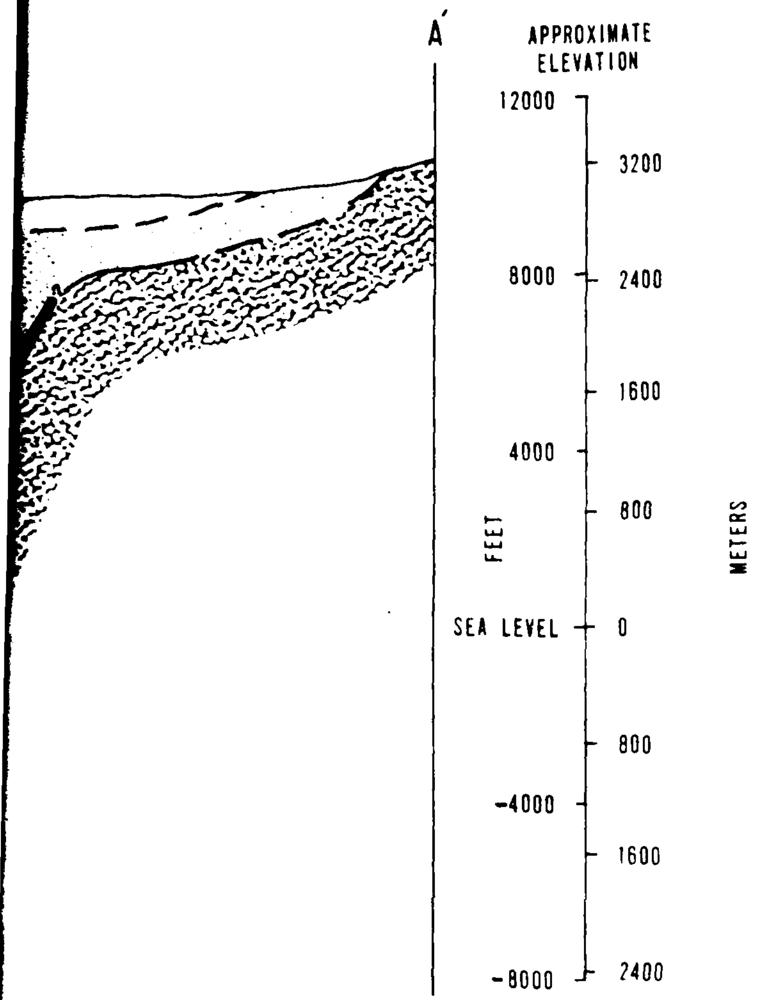
s, eolian, playa, and fluvial deposits

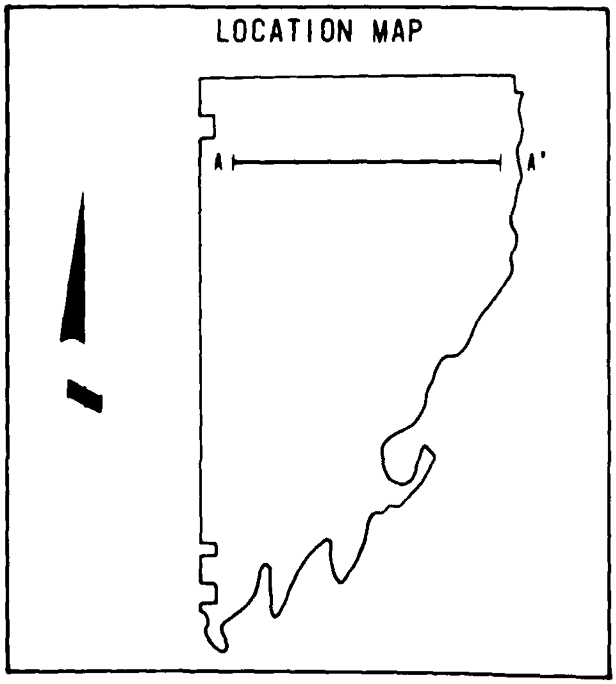
s

etation



Horizontal
Vertical Sc
Vertical Ex





Horizontal Scale: 1" ≈ 2 Miles (3 km)
Vertical Scale: 1" = 4000 Feet (1219 m)
Vertical Exaggeration: 2.6x

GENERALIZED GEOLOGIC CROSS SECTION
JORNADA DEL MUERTO, NEW MEXICO
RIO GRANDE CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE 3.7-6

FUGRO NATIONAL, INC.

3.7.3 Engineering and Geophysical Properties

Engineering and geophysical properties of the predominant geologic units are summarized in Table 3.7-3 and Figures 3.7-7 and 3.7-8. Eolian sheet sand consists of medium dense to dense silty and clayey sand with little gravel. Intermediate alluvial fan deposits consist of dense to very dense sands and gravels. Younger alluvial fan deposits are comprised of medium dense to dense silty and clayey sands with some stiff silts and clays. Older lacustrine deposits consist of stiff to very stiff silts and clays which are moderately compressible. Eolian sheet sand and intermediate alluvial fan deposits possess moderately high shear strength; younger alluvial fan and older lacustrine deposits possess moderate shear strength.

3.7.4 Conclusions

The following favorable and unfavorable geotechnical conditions for deployment of the MX system at Jornada del Muerto are based on the results of the Characterization study.

Favorable conditions:

- o Terrain is generally flat (less than 1.5 percent slope) requiring little preconstruction grading.
- o Drainages are typically shallow (less than 5 feet; 1.5 m) minimizing the need for major drainage structures.
- o A good network of roads exists at present in the site area. For construction of new roads, most of the surficial soils have good support characteristics for use as road subgrade.

ENGINEERING AND GEOPHYSICAL PROPERTIES		
	Eolian sheet sand (A3s)	Intermediate alluvial fan d
UNIFIED SOIL CLASSIFICATION SYMBOL(S)	SP, SM, SC	SP, SM, SC, GP, GM,
GENERAL PROPERTIES		
DRY DENSITY pcf(kg m^3)	100-120 (1602-1922)	95-133 (1522-2130)
MOISTURE CONTENT (%)	7-17	7-19
DEGREE OF SATURATION (%)	30-78	47-83
SPECIFIC GRAVITY	2.64-2.66	2.68-2.77
DEGREE OF CEMENTATION	None to moderate	Moderate to stro
COMPRESSIONAL WAVE VELOCITIES fps(mps)	1420-3220 (433-981)	1000-7200 (305-21
ELECTRICAL CONDUCTIVITY (mhos m)	DNA	DNA
GRAIN SIZE DISTRIBUTION (%)		
BOULDERS >12 inches(30cm)	0-5	0-3
COBBLES 3 to 12 inches(8to 30cm)	0-5	0-10
GRAVEL	0-12	0-90
SAND	50-97	5-95
SILT AND CLAY	3-50	5-48
PLASTICITY DATA		
LIQUID LIMIT	20±	24-26
PLASTICITY INDEX	NP-7	NP-12
COMPRESSIBILITY DATA		
COMPRESSION AT 4 ksf(192kN/m^2) (%)	DNA	DNA
SWELL OR COLLAPSE UPON SATURATION (%)	DNA	DNA
SHEAR STRENGTH DATA		
UNCONFINED COMPRESSION ksf(kN m^2)	DNA	2.0± (96±)
CD TRIAXIAL COMPRESSION	c = 0-1.0 ksf (48 kN/m^2), ϕ = 34°-39°	DNA
DIRECT SHEAR ksf(kN m^2)	0.7-5.5 (34-263)	2.5-7.7 (120-36
COMPACTION AND CBR DATA		
MAXIMUM DRY DENSITY pcf(kg m^3)	125-138 (2002-2211)	DNA
OPTIMUM MOISTURE CONTENT (%)	6.0-8.5	DNA
CBR AT 90% RELATIVE COMPACTION	7±	DNA

DNA - DATA NOT AVAILABLE (INSUFFICIENT DATA OR TESTS NOT PERFORMED)

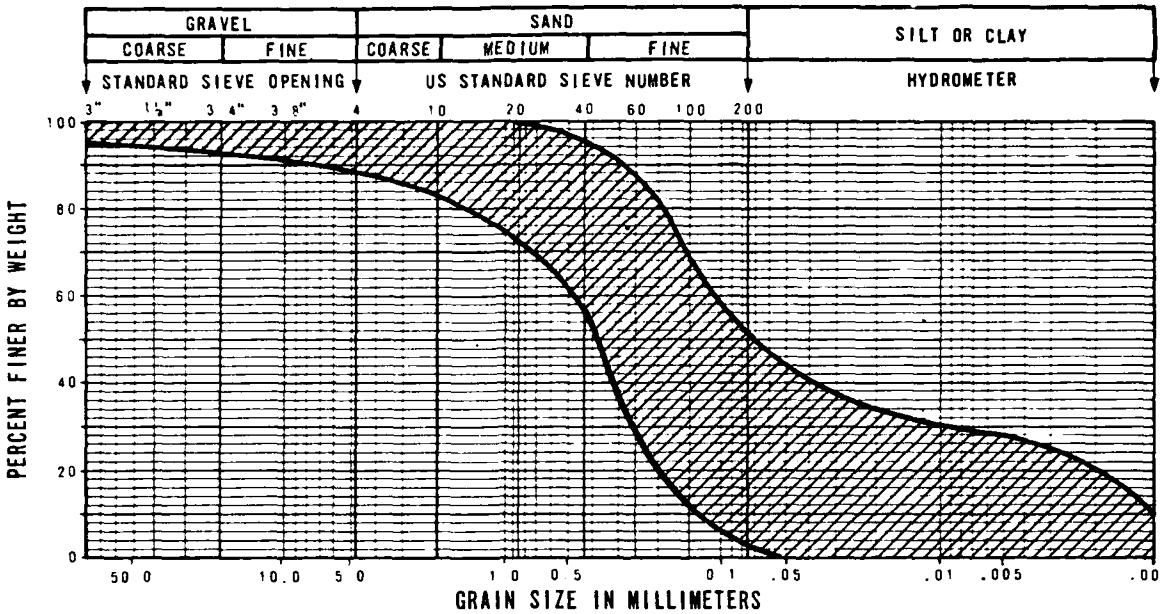
GEOLOGIC UNITS		
diate alluvial fan deposits (A5i)	Younger alluvial fan deposits (A5y)	Older lacustrine deposits (A4o)
SP, SM, SC, GP, GM, GC	SM, SC, ML, CL	CL, ML, SC
95-133 (1522-2130)	80-116 (1281-1858)	84-120 (1346-1922)
7-19	4-20	3-43
47-83	19-49	10-89
2.68-2.77	2.67-2.72	2.59-2.73
Moderate to strong	None to weak	Weak to strong
1000-7200 (305-2195)	1500-3100 (457-945)	1700-6750 (518-2057)
DNA	DNA	DNA
0-3	0-3	0
0-10	0-10	0
0-90	0-20	0-15
5-95	7-75	5-95
5-48	10-85	5-95
24-26	24-27	21-66
NP-12	NP-13	NP-31
DNA	DNA	1.5-4.5
DNA	DNA	0.1-3.0 (Swell)
2.0± (96±)	0.75± (36±)	0.2-8.2 (10-393)
DNA	DNA	c = 0-1.5 ksf (72 kN/m^2), ϕ=18°-34°
2.5-7.7 (120-369)	DNA	1.7-6.7 (81-321)
DNA	136± (2179±)	121-126 (1938-2018)
DNA	6.0±	9.0-9.5
DNA	10±	2-5

RANGE OF ENGINEERING AND GEOPHYSICAL PROPERTIES JORNADA DEL MUERTO, NEW MEXICO

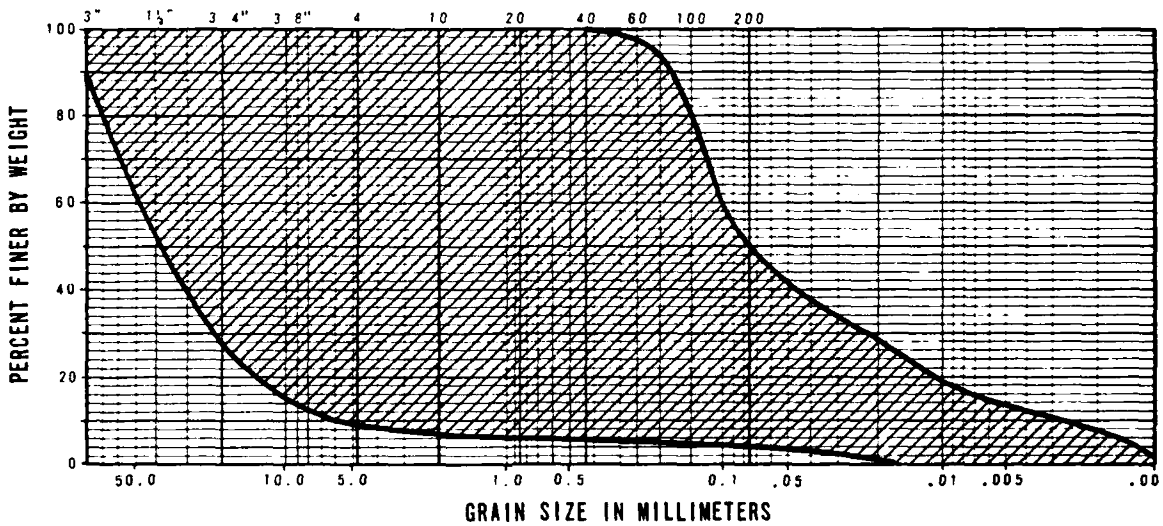
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

TABLE 3.7-3

FUGRO NATIONAL, INC.



A3s



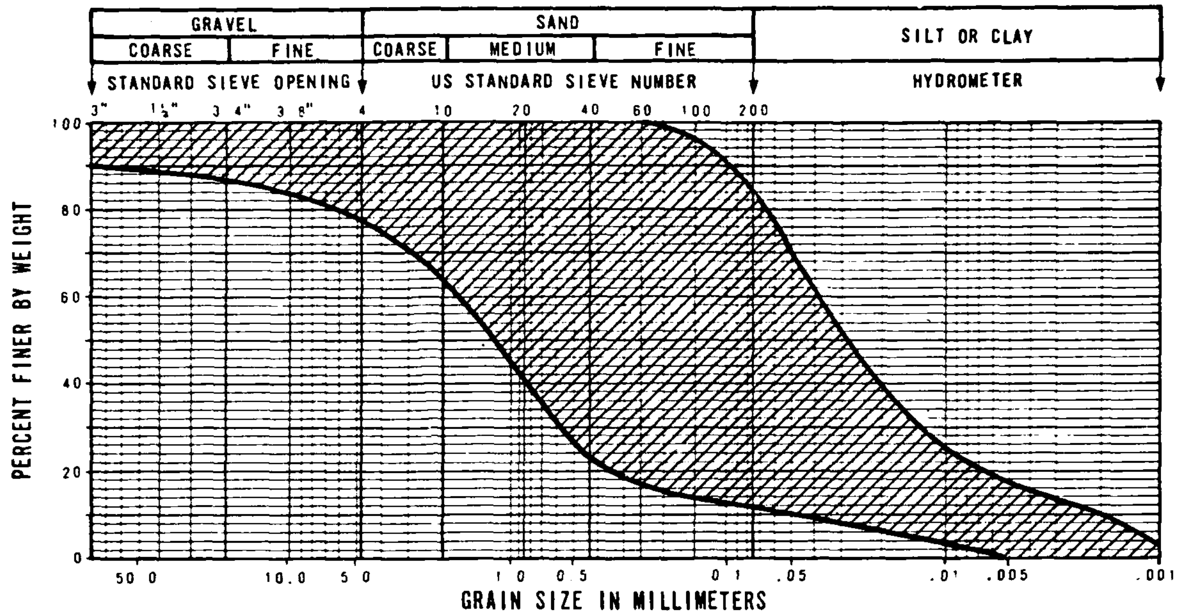
A5i

RANGE OF GRADATION OF GEOLOGIC UNITS
JORNADA DEL MUERTO, NEW MEXICO
RIO GRANDE CSP

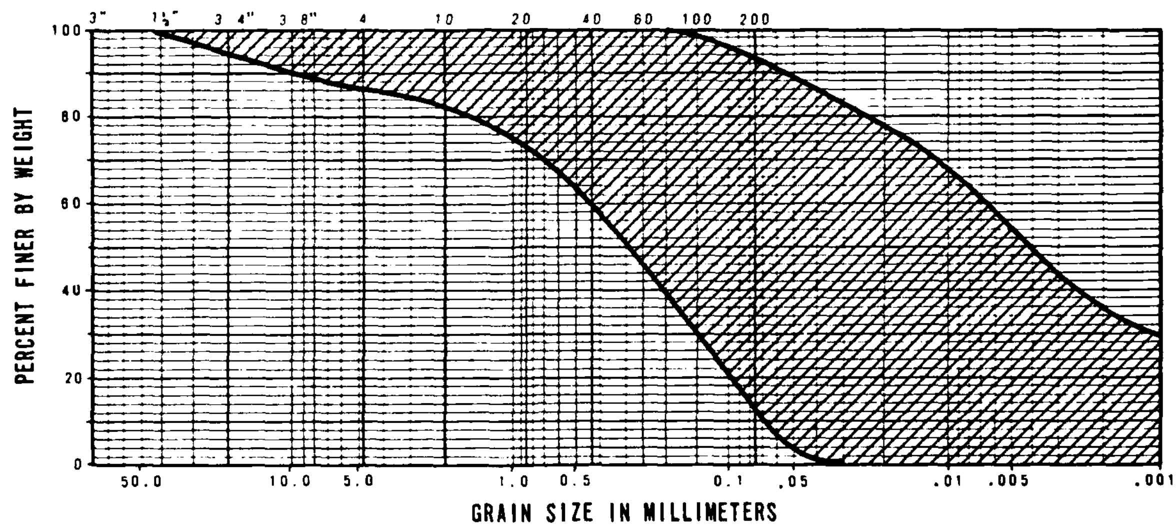
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.7-7

FUGRO NATIONAL, INC.



A5y



A4o

RANGE OF GRADATION OF GEOLOGIC UNITS
JORNADA DEL MUERTO, NEW MEXICO
RIO GRANDE CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.7-8

FUGRO NATIONAL, INC.

- Soils are suitable for: excavation of vertical shelters using augers, continuous trenches by an MX trencher, and conventional excavations required for horizontal shelters. Suitability of soils for backfilling and compaction in trench excavations is good.

- Sufficient quantities of aggregate and water required for roads and concrete are available within and adjacent to the site area.

- Depth to rock over a major portion of the site is greater than 150 feet (46 m).

- Land is owned by White Sands Missile Range.

Unfavorable conditions:

- In approximately 25 percent of the area, vertical cuts in the soils will not be stable during excavation for vertical shelters and trenches, thus requiring additional expense.

- In approximately 25 percent of the area, the surficial soils do not have good support characteristics for use as road subgrade, thus requiring additional cost.

- In the southeastern portion of the site, depth to ground water ranges from less than 50 feet (15 m) to greater than 150 feet (46 m). In areas where the depth to ground water is less than 120 feet (37 m), additional costs for excavation of vertical shelters will be required.

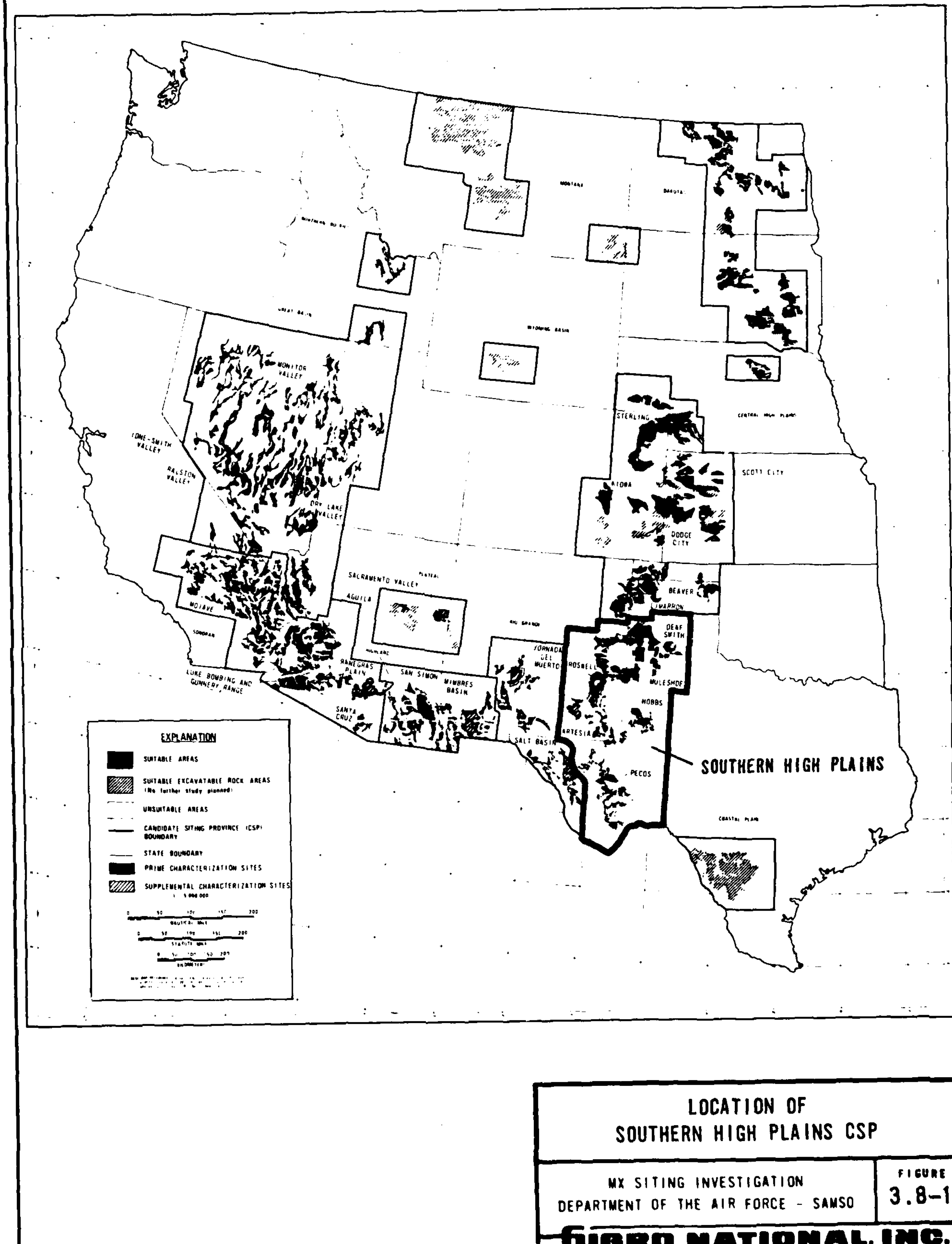
In summary, the Jornada del Muerto characterization site presents favorable geotechnical conditions for deployment of the present MX basing mode concepts.

3.8 MULESHOE SITE: SOUTHERN HIGH PLAINS CSP

The Southern High Plains CSP covers portions of western Texas and eastern New Mexico (Figure 3.8-1). More than 80 percent of the suitable area is privately owned. The remaining land is federal or state controlled rangeland, school sections, and rights-of-way. Land is used principally for agriculture with 46 percent being used as rangeland and 37 percent as farmland.

The CSP is characterized by flat plains, rolling hills and valleys, with local stream incisions. Most of the CSP lies within the Great Plains physiographic province. A small portion of the southern tip lies within the Basin and Range physiographic province and consists of broad alluvium-filled valleys or basins bounded by north to northwest trending fault-controlled mountain ranges. Six characterization sites were selected based on a review of regional geologic and engineering data (Figure 3.8-2). The Muleshoe site typifies the geotechnical conditions found in the northern 60 percent of the CSP.

The Muleshoe site is approximately 450 nm^2 (1544 Km^2) in area, and covers portions of Bailey and Cochran Count.es, Texas. Field activities at the site are shown in Figure 3.8-3. Both the field and the laboratory activities are summarized in Table 3.8-1.

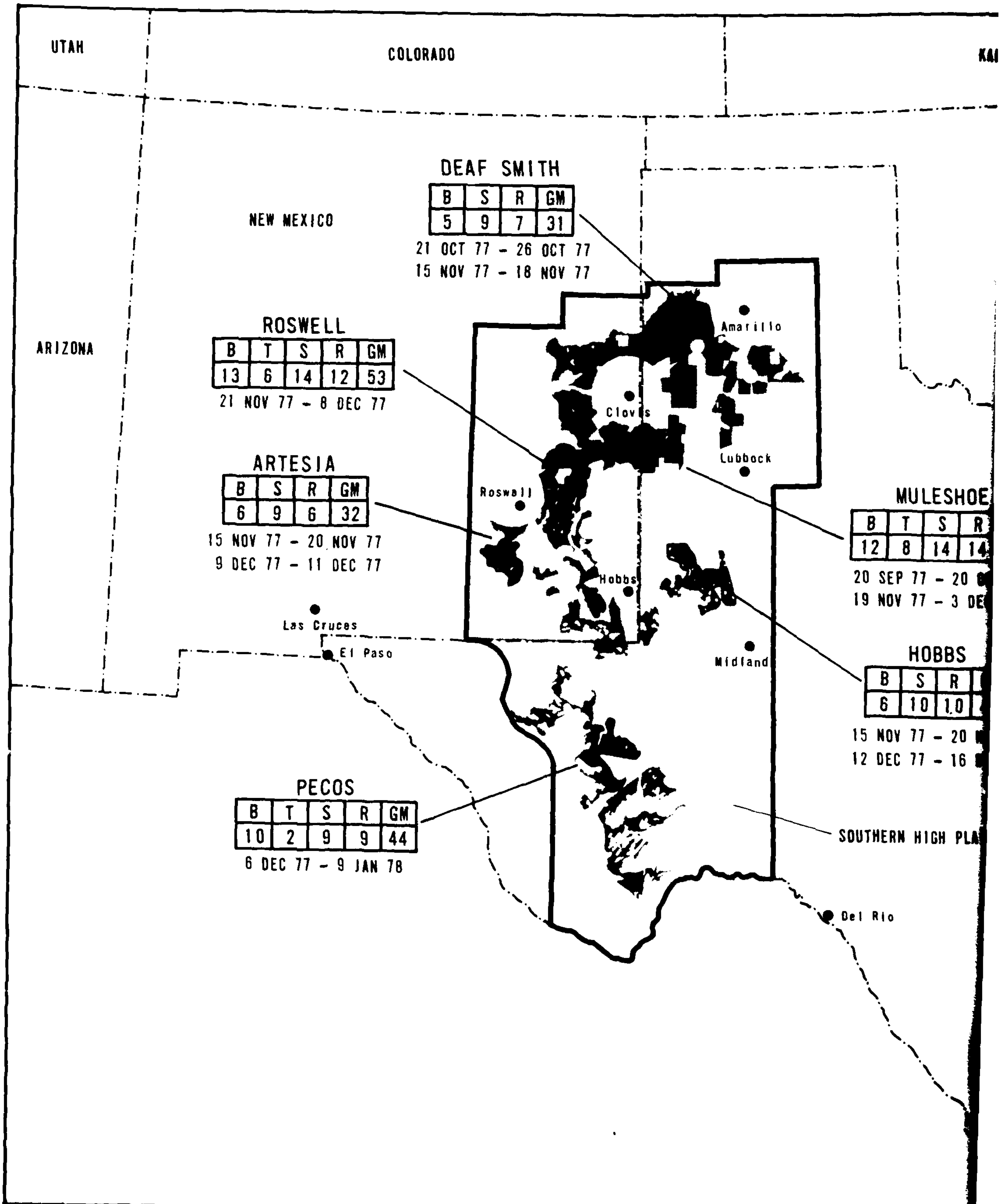


LOCATION OF
SOUTHERN HIGH PLAINS CSP

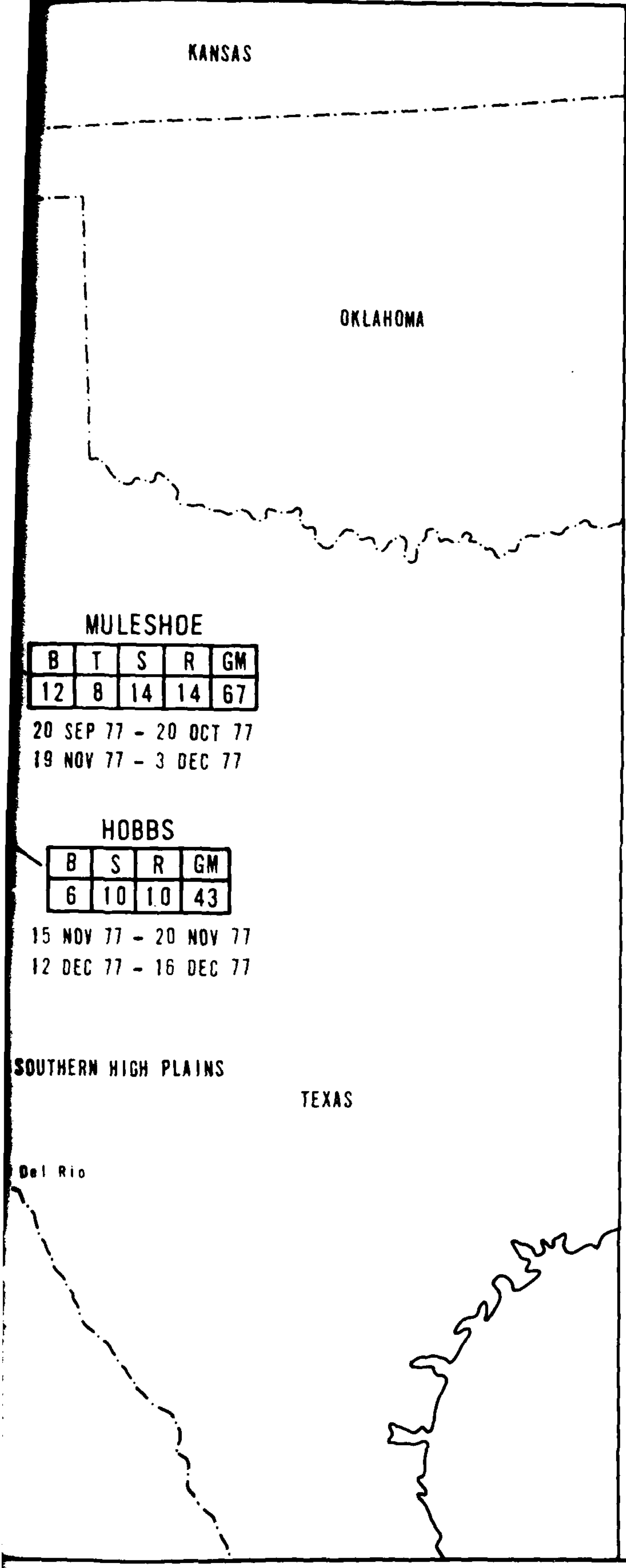
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.8-1

FUGRO NATIONAL, INC.



UTAH
COLORADO
KA
NEW MEXICO
ARIZONA
DEAF SMITH
B S R GM
5 9 7 31
21 OCT 77 - 26 OCT 77
15 NOV 77 - 18 NOV 77
ROSWELL
B T S R GM
13 6 14 12 53
21 NOV 77 - 8 DEC 77
ARTESIA
B S R GM
6 9 6 32
15 NOV 77 - 20 NOV 77
9 DEC 77 - 11 DEC 77
Amarillo
Clovis
Lubbock
Roswell
Hobbs
Midland
Las Cruces
El Paso
Del Rio
MULESHOE
B T S R
12 8 14 14
20 SEP 77 - 20
19 NOV 77 - 3 DE
HOBBS
B S R
6 10 10
15 NOV 77 - 20
12 DEC 77 - 16
PECOS
B T S R GM
10 2 9 9 44
6 DEC 77 - 9 JAN 78
SOUTHERN HIGH PLA



EXPLANATION

ACTIVITIES

B - BORINGS

T - TRENCHES

S - SHALLOW SEISMIC REFRACTION LINES

R - ELECTRICAL RESISTIVITY LINES

GM - GEOLOGIC RECON MAPPING STATIONS

B	T
12	8

— Activity
— Quantity of each activity

SUITABLE AREA

SUITABLE ROCK AREA

PRIME SITE

SUPPLEMENTAL SITE

0 50 100 150 200
NAUTICAL MILES

0 50 100 150 200
STATUTE MILES

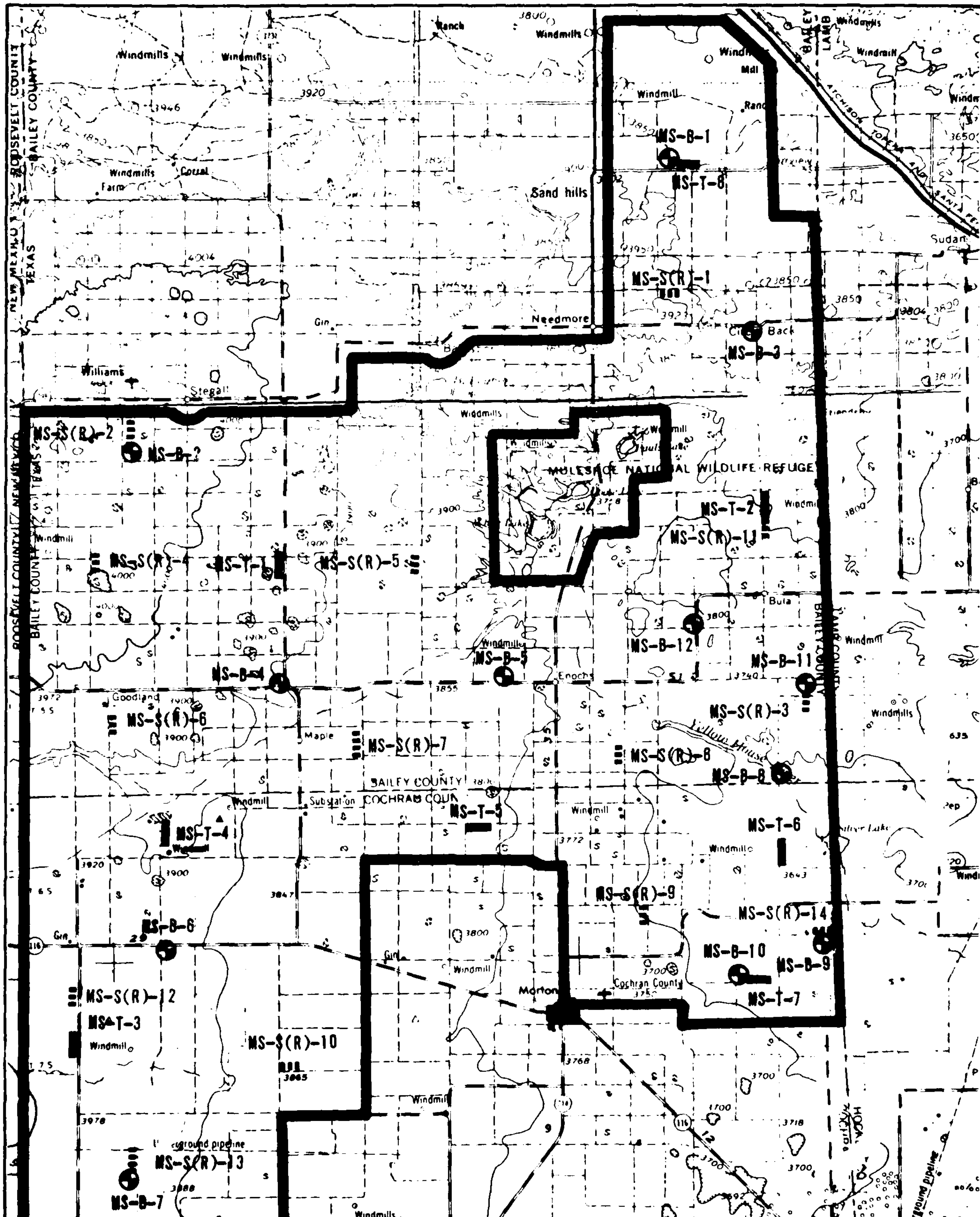
0 50 100 150 200
KILOMETERS

CHARACTERIZATION SITES
AND FIELD ACTIVITIES
SOUTHERN HIGH PLAINS CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE 3.8-2

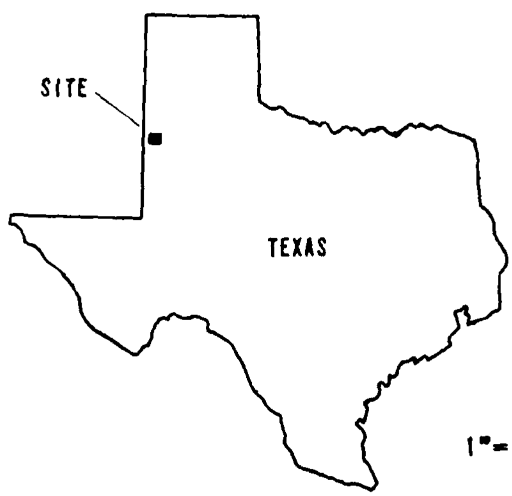
FUGRO NATIONAL, INC.


MULESHOE NATIONAL WILDLIFE REFUGE
MS-B-1
MS-T-8
MS-S(R)-1
MS-B-3
MS-S(R)-2
MS-B-2
MS-T-2
MS-S(R)-11
MS-S(R)-4
MS-T-1
MS-S(R)-5
MS-B-12
MS-B-11
MS-B-5
MS-B-4
MS-S(R)-3
MS-S(R)-6
MS-S(R)-7
MS-S(R)-8
MS-B-8
MS-T-5
MS-T-4
MS-T-6
MS-S(R)-9
MS-S(R)-14
MS-B-6
MS-B-10
MS-B-9
MS-T-7
MS-S(R)-12
MS-T-3
MS-S(R)-10
MS-S(R)-13
MS-B-7
BAILEY COUNTY
COCHRAN COUNTY
ROOSEVELT COUNTY
NEW MEXICO
TEXAS
Sand hills
Needmore
Williams
Stegall
Goodland
Maple
Substation
Enochs
Bula
Morton
Lehman
Bledsoe
Sudan
Cochran County
Underground pipeline
Windmills
Windmill
Gin
Farm
Corral
Ranch

EXPLANATION

- Boring
- Seismic refraction (S) and resistivity (R) lines
- Trench

SITE LOCATION



1:250,000
1" = 3.2 Nautical Miles

ACTIVITY LOCATION MAP
MULESHOE, TEXAS
SOUTHERN HIGH PLAINS CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.8-3

FUGRO NATIONAL, INC.

GEOLOGY AND GEOPHYSICS

TYPE OF ACTIVITY	NUMBER OF ACTIVITIES
Geological mapping stations	67
Shallow refraction	14
Electrical resistivity	14

ENGINEERING

NUMBER OF BORINGS	DEPTH FEET(METERS)
7	50 (15)
4	100 (30)
1	300 (91)
NUMBER OF TRENCHES	**DEPTH FEET(METERS)**
8	12 (4)

ENGINEERING-LABORATORY TESTS

TYPE OF TEST	NUMBER OF TESTS
Moisture/density	90
Specific gravity	10
Sieve analysis	38
Hydrometer	32
Atterberg limits	32
Consolidation	3

TYPE OF TEST	NUMBER OF TESTS
Unconfined compression	5
Triaxial compression	6
Direct shear	6
Compaction	3
CBR	3
Chemical analysis	4

SCOPE OF FIELD AND LABORATORY ACTIVITIES
MULESHOE, TEXAS

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE 3.8-1

FUGRO NATIONAL, INC.

3.8.1 Surficial Geology and Terrain

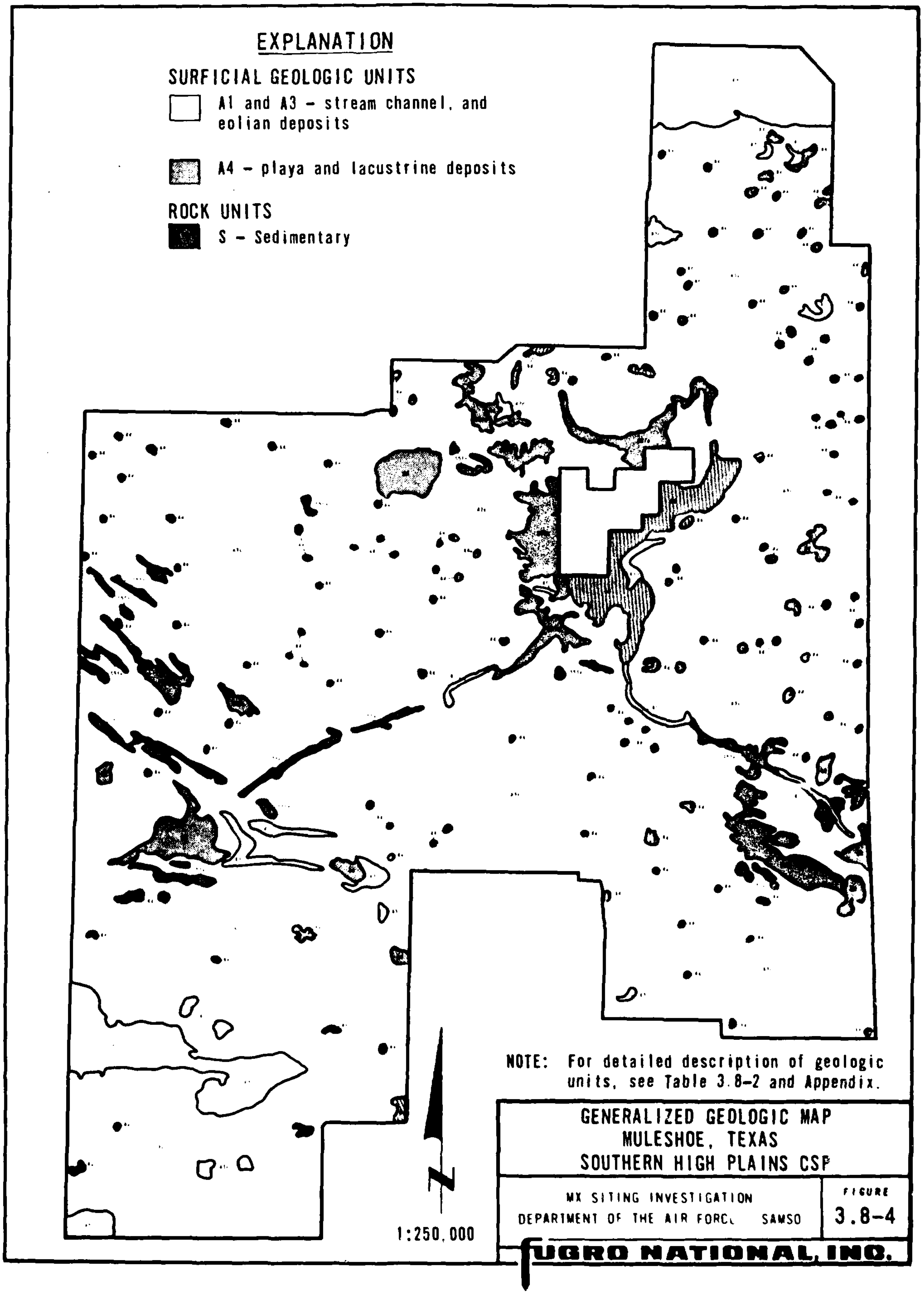
Eolian deposits which may be more than 100 feet (30 m) thick, cover 93 percent of the Muleshoe site (Figure 3.8-4 and Table 3.8-2). These deposits form a mantle of sheet sand (A3s) and dune sand (A3d) which overlies the Ogallala Formation. The eolian deposits are principally clayey and silty sands that have varying degrees of caliche cementation. Approximately five percent of the A3s deposits contain moderate to strongly cemented caliche horizons which are a few inches to tens of feet thick.

Other surficial units include fluvial (A1) and playa and lacustrine deposits (A4) which together comprise five percent of the Muleshoe site. These deposits consist of mixtures of sand, silt, and clay and range in thickness from ten to 30 feet (3 to 9 m). The Ogallala Formation is exposed over only two percent of the site.

The Muleshoe site is a broad, nearly featureless plain incised by widely spaced streams along the margins and dotted by numerous small natural depressions or playas. Surface slopes are generally less than three percent, except in dune areas. Stream incisions and playas are less than 30 feet (9 m) deep, are relatively broad, and have subtle banks.

3.8.2 Subsurface Conditions

The soils found in the subsurface are illustrated in Figure 3.8-5. The Pliocene Ogallala Formation underlies all of the


EXPLANATION
SURFICIAL GEOLOGIC UNITS
A1 and A3 - stream channel, and eolian deposits
A4 - playa and lacustrine deposits
ROCK UNITS
S - Sedimentary
N
1:250,000
NOTE: For detailed description of geologic units, see Table 3.8-2 and Appendix.
GENERALIZED GEOLOGIC MAP
MULESHOE, TEXAS
SOUTHERN HIGH PLAINS CSP
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO
FIGURE
3.8-4
FUGRO NATIONAL, INC.

AD-A114 214 FUGRO NATIONAL INC LONG BEACH CA F/G 8/6
MX SITING INVESTIGATION GEOTECHNICAL SITING STATUS REPORT, VOLU--ETC(U)
JUN 78 F04704-77-C-0010
UNCLASSIFIED FN-78-JUN-VOL-1 NL

3 of 4
AD
A114214

ENGINEERING GEOLOGY UNIT (e)	GEOLOGIC AGE	THICKNESS FEET (METERS) (a)	DESCRIPTIVE NAME(S)	USCS SYMBOL(S)	AREAL EXTENT (	
					nm^2 (km^2)	PE
Fluvial Deposits (A1)	Quaternary	10-30 (3-8)	Sandy Clay and Silty Sand	SM	5 (15)	
Eolian Deposits, Dune Sand (A3d)	Quaternary	5-30 (1.5-9)	Silty Sand and Sand	SP	81 (277)	
Eolian Deposits, Sheet Sand (A3s)	Quaternary	10-100 (3-31)	Sandy Clay and Clayey to Silty Sand	SC, SM	338 (1154)	
Playa Deposits (A4)	Quaternary	10-20 (3-6)	Silty Clay Silty Sand	SM	18 (62)	
Ogallala Formation (S5To)	Pliocene	50-100 (15-46)	Sandy Clay and Clayey to Silty Sand	CL, SC, SM	9 (31)	

NOTES:

(a) Thickness range represents the most common occurrence.

(b) A3s deposits locally contain moderate to well-indurated caliche (five percent of site).

(c) A well-indurated pisolitic and brecciated caliche caprock occurs extensively in the upper few feet of the formation.

(d) Maximum grain size based on visual observations; engineering test data indicates larger particle sizes due to fragmentation of caliche.

(e) For generic description of geologic units, see Appendix.

)	AREAL EXTENT (SITE)		PROPERTIES OF SURFACE MATERIALS					SURFACE MORPHOLOGY		NOTES
	nm^2 (km^2)	PERCENT	GRADATION	CEMENTATION	MAXIMUM GRAIN SIZE	PAVEMENT/ PATINA	STAGE OF CALICHE	SLOPE (PERCENT)	DRAINAGE DEPTHS FEET(METERS)	
	5 (15)	1	Poor	None	Sand	Not Applicabe	None	1-3	10-20 (3-6)	
	81 (277)	18	Poor	None-Weak	Sand	Not Applicable	None-I	5-40	None	
	338 (1154)	75	Poor	Weak-Strong	Sand	Not Applicable	I-IV	0-8	10-20 (3-6)	(b) (d)
	18 (62)	4	Poor	None-Weak	Sand	Not Applicable	None-I	0-3	15-30 (5-9)	
C.	9 (31)	2	Poor	Weak-Very Strong	Gravel	Not Applicable	I-IV	0-3	10-20 (3-6)	(c) (d)

of site).
n the

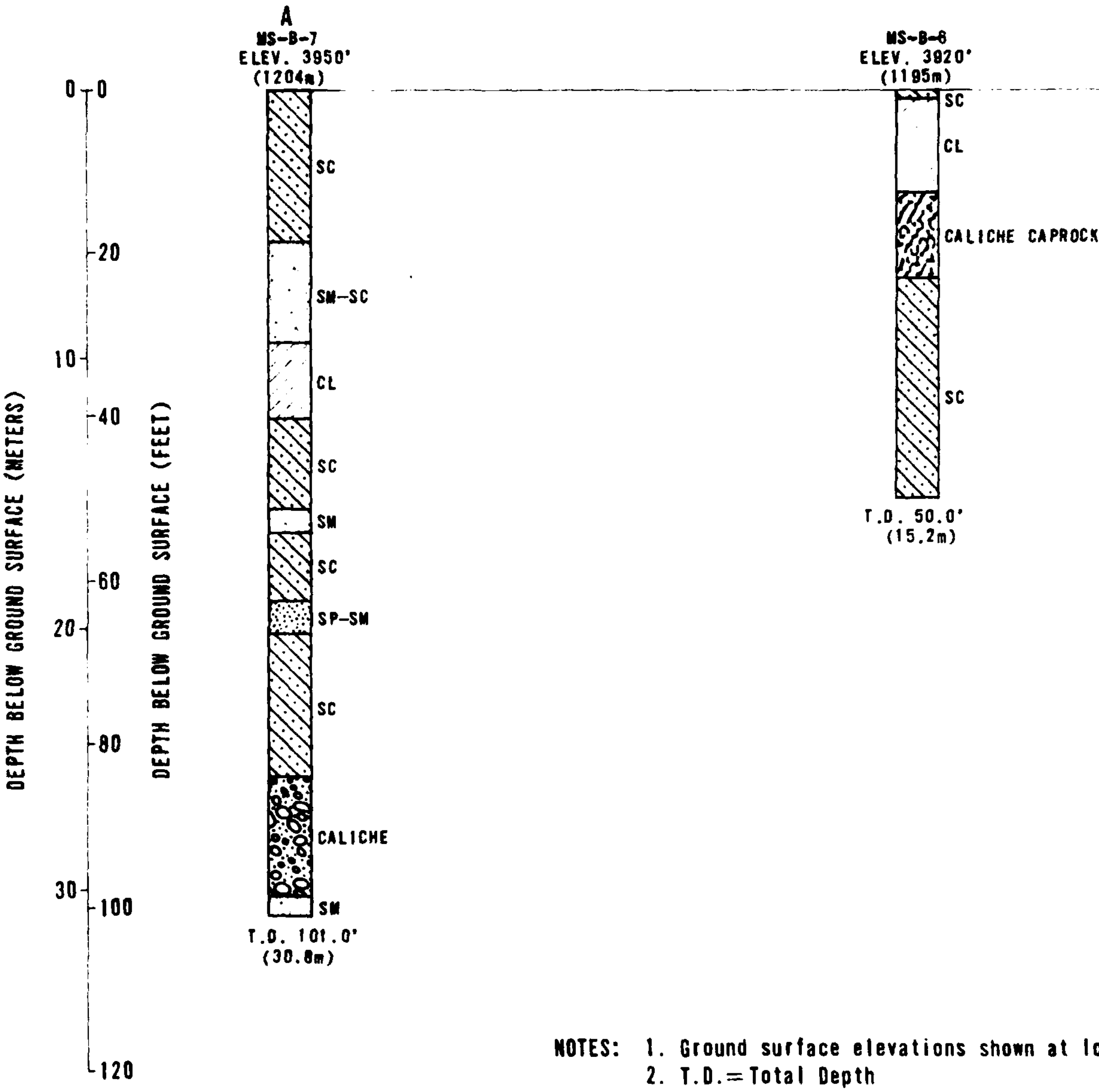
tes

DESCRIPTION OF SURFICIAL GEOLOGIC UNITS MULESHOE, TEXAS

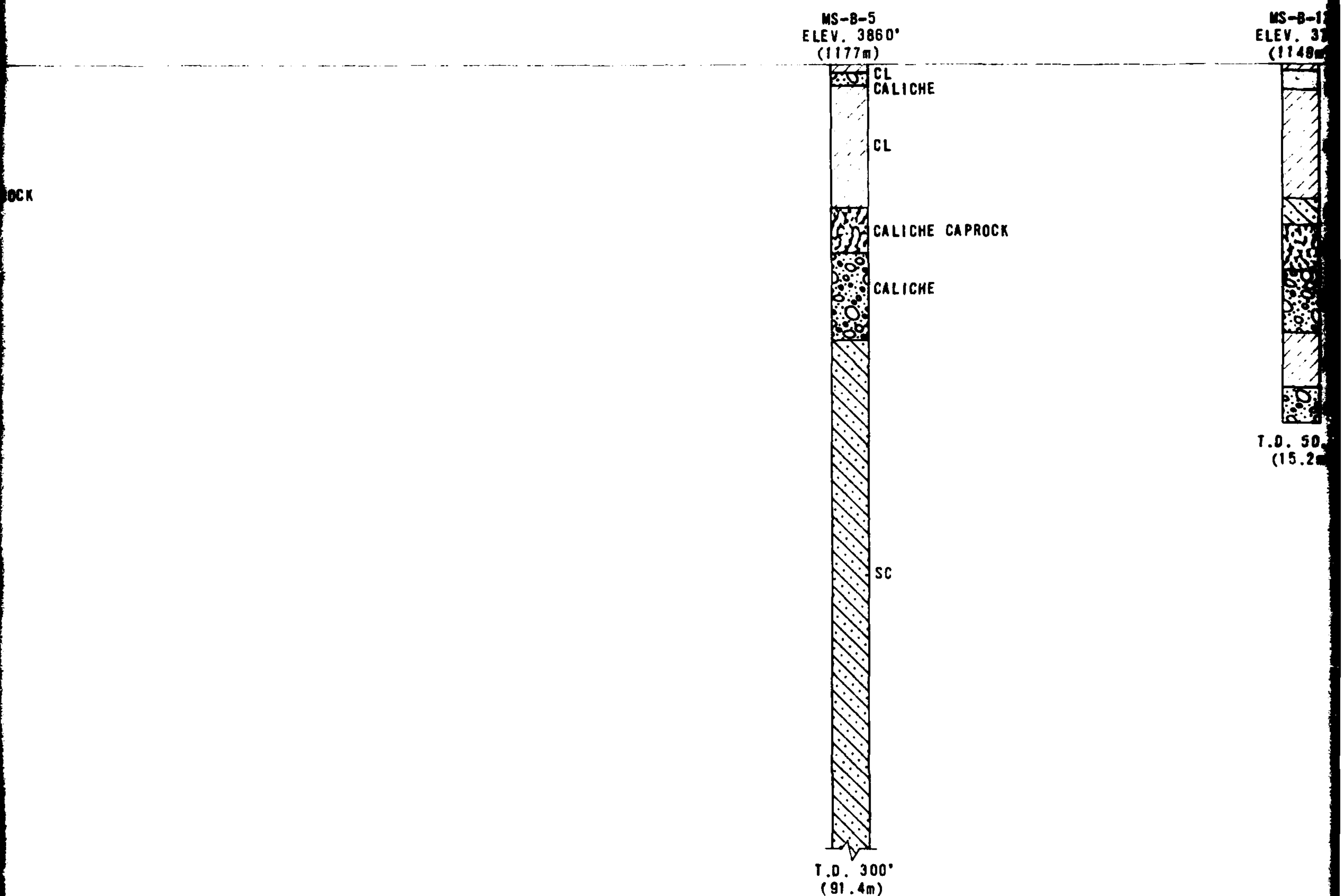
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

TABLE 3.8-2

FUGRO NATIONAL, INC.

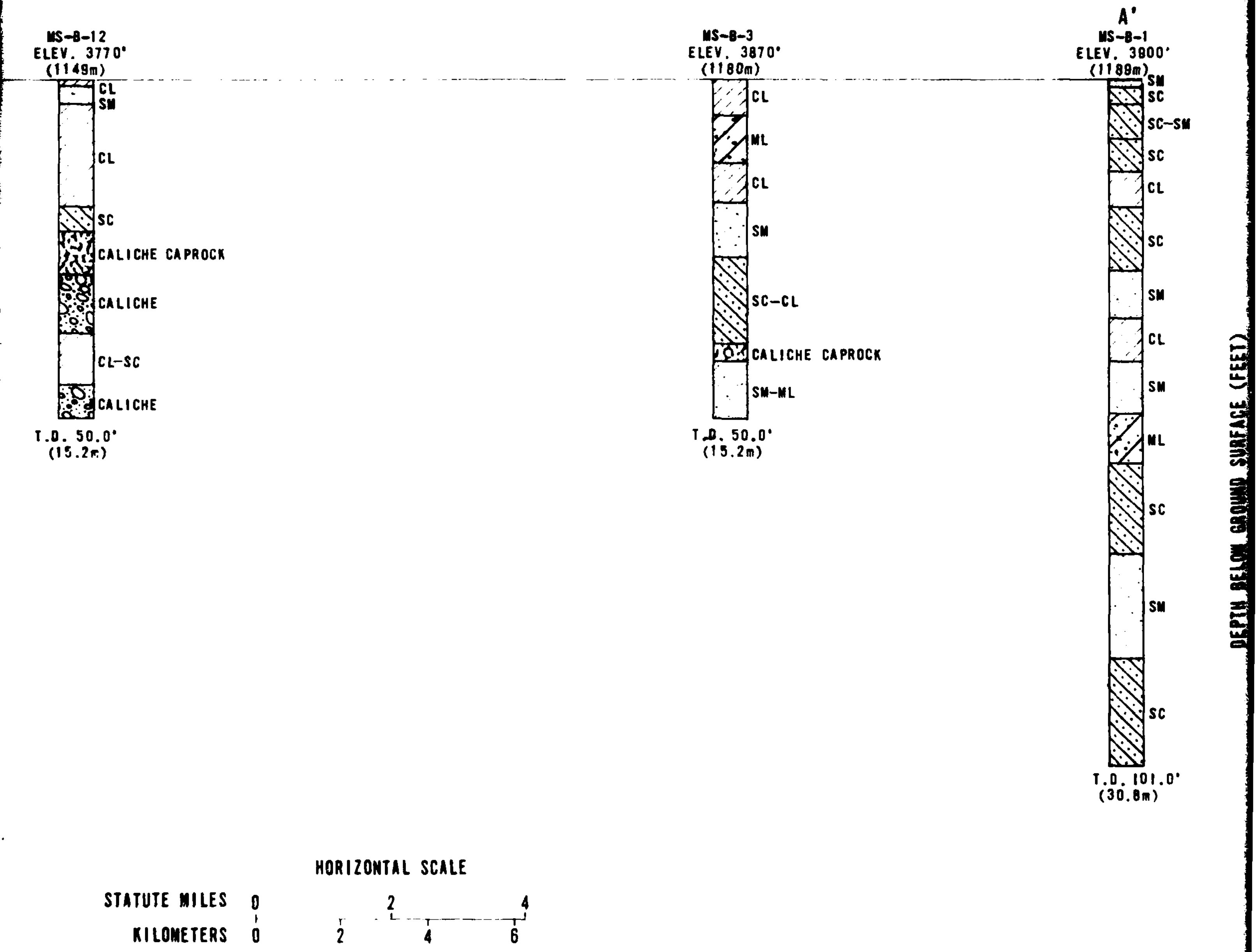


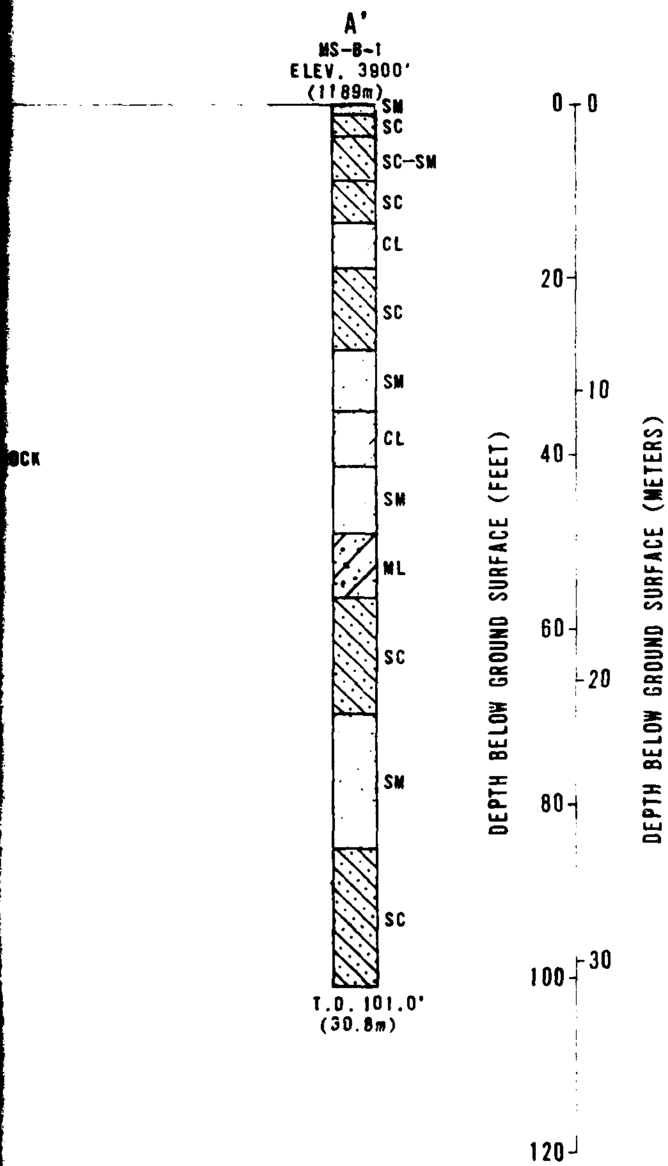
NOTES: 1. Ground surface elevations shown at locations o
2. T.D.= Total Depth
3. Soil types shown adjacent to soil column are b
(USCS) and are explained in the appendix

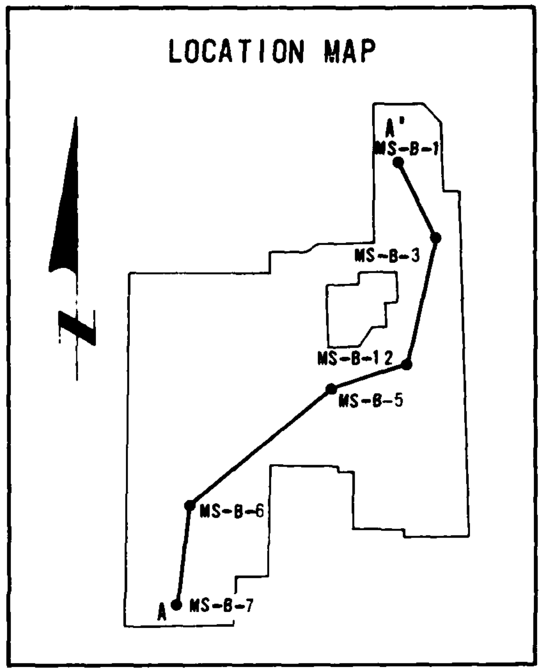


locations of borings are approximate

column are based on Unified Soil Classification System
ppendix


A'
MS-B-12
ELEV. 3770'
(1149m)
CL
SM
CL
SC
CALICHE CAPROCK
CALICHE
CL-SC
CALICHE
T.D. 50.0'
(15.2m)
MS-B-3
ELEV. 3870'
(1180m)
CL
ML
CL
SM
SC-CL
CALICHE CAPROCK
SM-ML
T.D. 50.0'
(15.2m)
MS-B-1
ELEV. 3900'
(1189m)
SM
SC
SC-SM
SC
CL
SC
SM
CL
SM
ML
SC
SM
SC
T.D. 101.0'
(30.8m)
DEPTH BELOW GROUND SURFACE (FEET)
HORIZONTAL SCALE
STATUTE MILES 0 2 4
KILOMETERS 0 2 4 6





SOIL PROFILE
MULESHOE, TEXAS
SOUTHERN HIGH PLAINS CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE 3.8-5

FUGRO NATIONAL, INC.

41

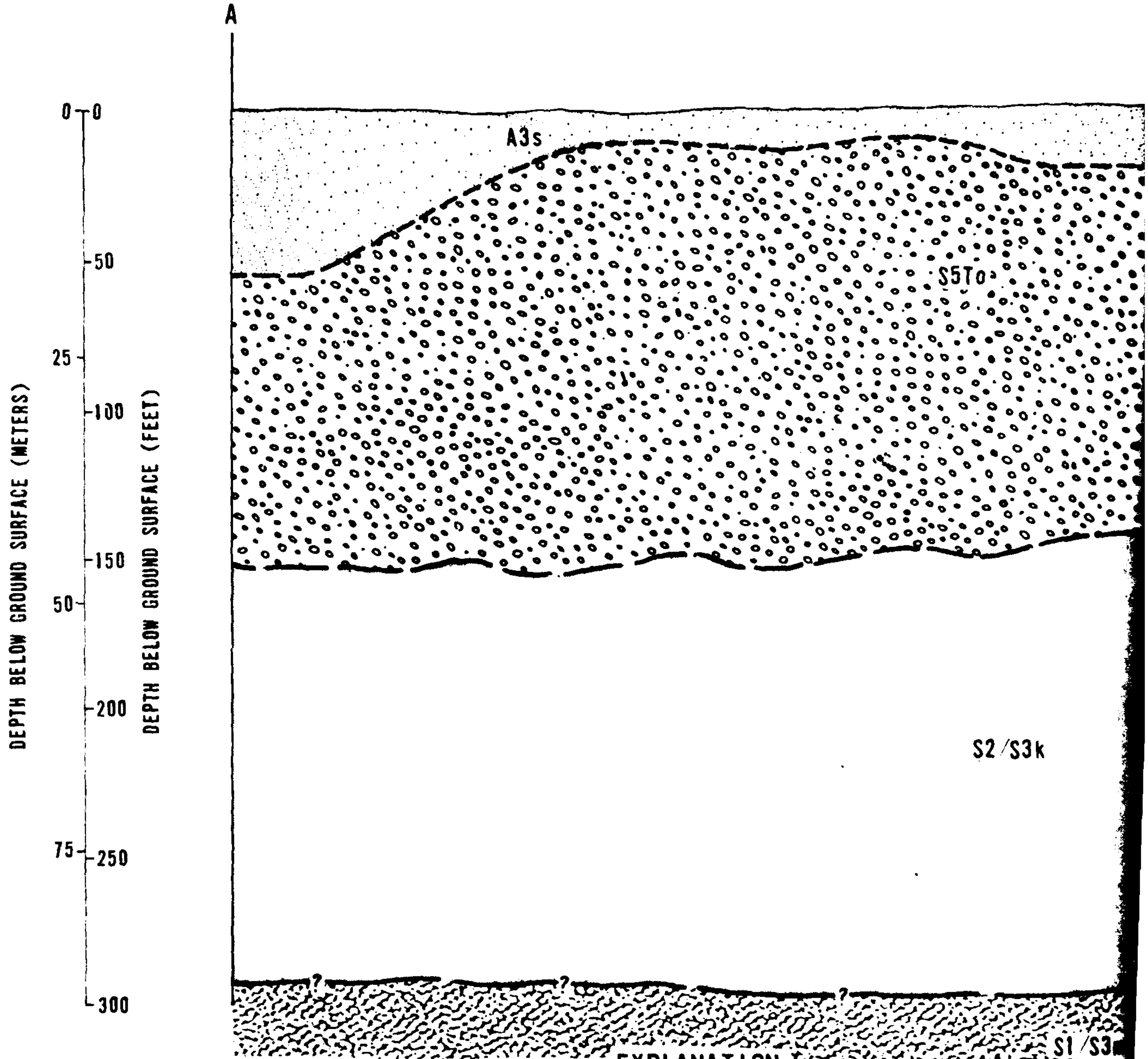
Muleshoe Site ranging in thickness from 50 to 100 feet (15 to 30 m). It is composed of beds and lenses of calcareous clay, silt, sand, gravel and caliche. The most important lithologic feature of the Ogallala Formation is the caprock, a well indurated, massive caliche which is pisolitic, brecciated, and silificified in part. The caprock ranges in thickness from a few inches to tens of feet and forms a prominent escarpment around the entire physiographic section.

Underlying the Ogallala Formation (Figure 3.8-6) are the Triassic Dockum Group (sandstone, siltstone and gypsum) and several Cretaceous formations (shale and limestone). The entire site is underlain by these excavatable rock units at depths less than 150 feet (46 m).

Ground water occurs at depths exceeding 100 feet (30 m) in 75 percent of the site. All published data indicate that the ground water is shallower than 150 feet (46 m) over most of the site, with the exception of the extreme southern tip.

3.8.3 Engineering and Geophysical Properties

Engineering and geophysical properties of the dominant geologic units are summarized in Table 3.8-3 and Figure 3.8-7. Sheet and dune sand deposits have been combined into a single category, eolian deposits, as their characteristics are similar. The properties of caliche found at the site are generally not included in Table 3.8-3 and Figure 3.8-7 due to insufficient data.

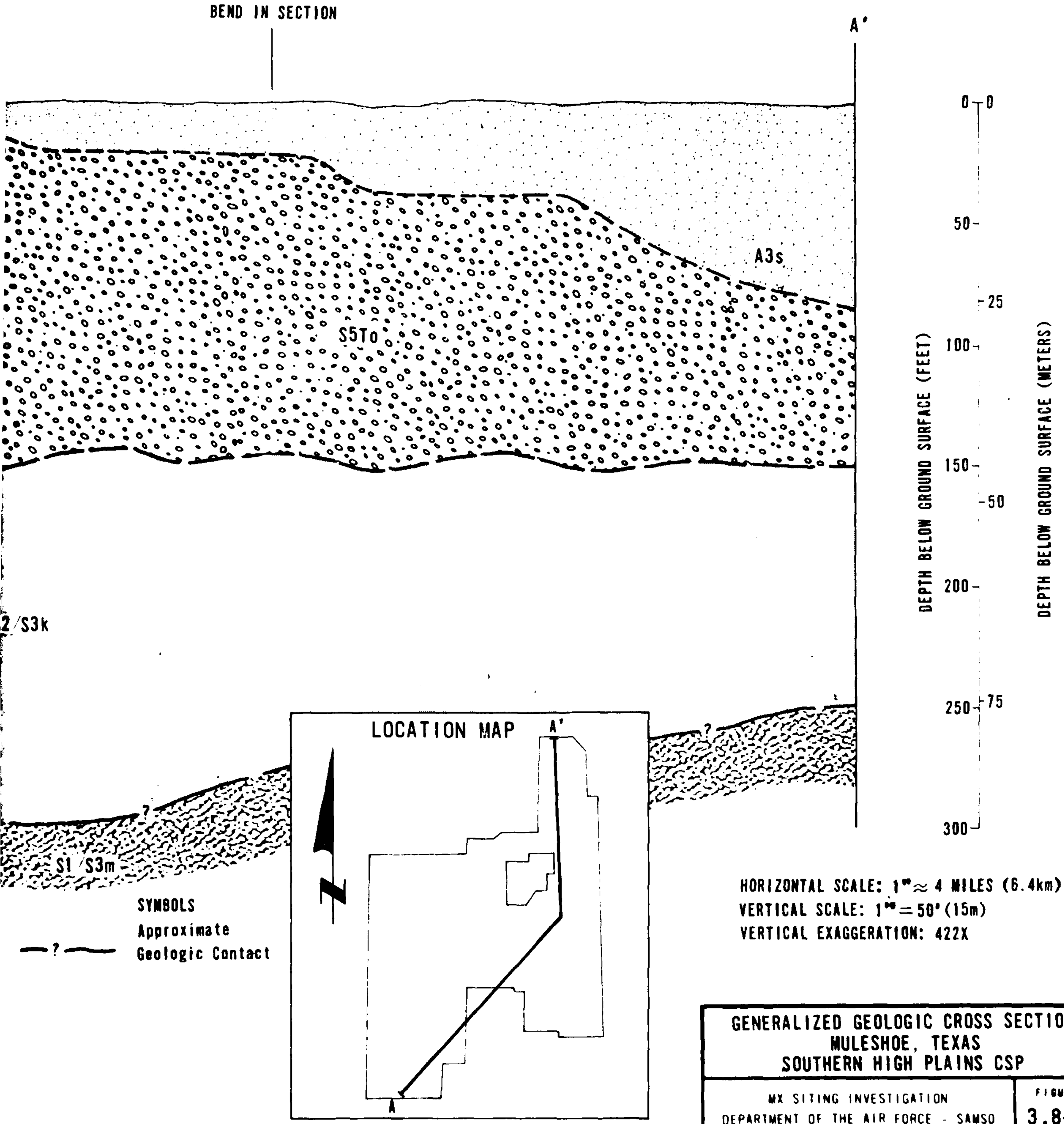


EXPLANATION

GEOLOGIC UNITS

A3s	Eolian Sheet Sand Deposits; locally includes fluvial (A1), dune (A3d), playa (A4) and Ogallala (S5To) deposits; average seismic velocity 1560-2550 fps (475-777 mps).
S5To	Ogallala Formation; Unconsolidated sand, silt, clay, and gravel with well-indurated caliche caprock; average seismic velocity 2700-10000 fps (823-3048 mps).
S2 S3k	Cretaceous Formations; Undifferentiated deposits limestone and shale; average seismic velocity 6000-10000 fps (1829-3048 mps).
S1 S3m	Dockum Group; Sandstone and siltstone interbedded with gypsum; average seismic velocity 6000-10000 fps (1829-3048 mps).

— ? —



GENERALIZED GEOLOGIC CROSS SECTION
MULESHOE, TEXAS
SOUTHERN HIGH PLAINS CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.8-6

FUGRO NATIONAL, INC.

ENGINEERING AND GEOPHYSICAL PROPERTIES*	Eolian sand deposits (A3s and A3d)	Ogallala form
UNIFIED SOIL CLASSIFICATION SYMBOL(S)	CL, SC, SM	CL, SC,
GENERAL PROPERTIES		
DRY DENSITY pcf(kg m^3)	90-120 (1442-1922)	95-125 (15
MOISTURE CONTENT (%)	5-20	5-25
DEGREE OF SATURATION (%)	30-100	30-1
SPECIFIC GRAVITY	2.6-2.7	2.6-2
DEGREE OF CEMENTATION	Weak to strong	Weak to ve
COMPRESSIONAL WAVE VELOCITIES fps(mps)	1560-2550 (475-777)	2700-10,000
ELECTRICAL CONDUCTIVITY (mhos m)	003- 044	001-
GRAIN SIZE DISTRIBUTION (%)		
BOULDERS >12 inches(30cm)	0	0
COBBLES 3 to 12 inches(8to 30cm)	0-5	0-
GRAVEL	0-40	0-
SAND	30-90	20-
SILT AND CLAY	5-70	10-
PLASTICITY DATA		
LIQUID LIMIT	NP-35	NP
PLASTICITY INDEX	NP-15	NP
COMPRESSIBILITY DATA		
COMPRESSION AT 4 ksf(192kN/m^2) (%)	1-2	
SWELL OR COLLAPSE UPON SATURATION (%)	0-0.5 (Swell)	0.1±
SHEAR STRENGTH DATA		
UNCONFINED COMPRESSION ksf(kN/m^2)	0.2-1 (10-48)	2± (
CD TRIAXIAL COMPRESSION	c = 0.5-1.5 ksf (24-72 kN m^2), ϕ = 25°-35°	c = 0.5-1.5 ksf (24-7
DIRECT SHEAR ksf(kN m^2)	1-5 (48-239)	4±
COMPACTION AND CBR DATA		
MAXIMUM DRY DENSITY pcf(kg m^3)	115-125 (1842-2002)	115-125
OPTIMUM MOISTURE CONTENT (%)	10-15	1
CBR AT 90% RELATIVE COMPACTION	5-40	5

DNA = DATA NOT AVAILABLE (INSUFFICIENT DATA OR TESTS NOT PERFORMED).

*PROPERTIES OF CALICHE GENERALLY NOT INCLUDED AS DATA IS INSUFFICIENT. DIFFERENT DEGREES OF CALICHE DEVELOPMENT IN EOLIAN DEPOSITS AND OGALLALA FORMATION AFFECTS ENGINEERING CHARACTERISTICS.

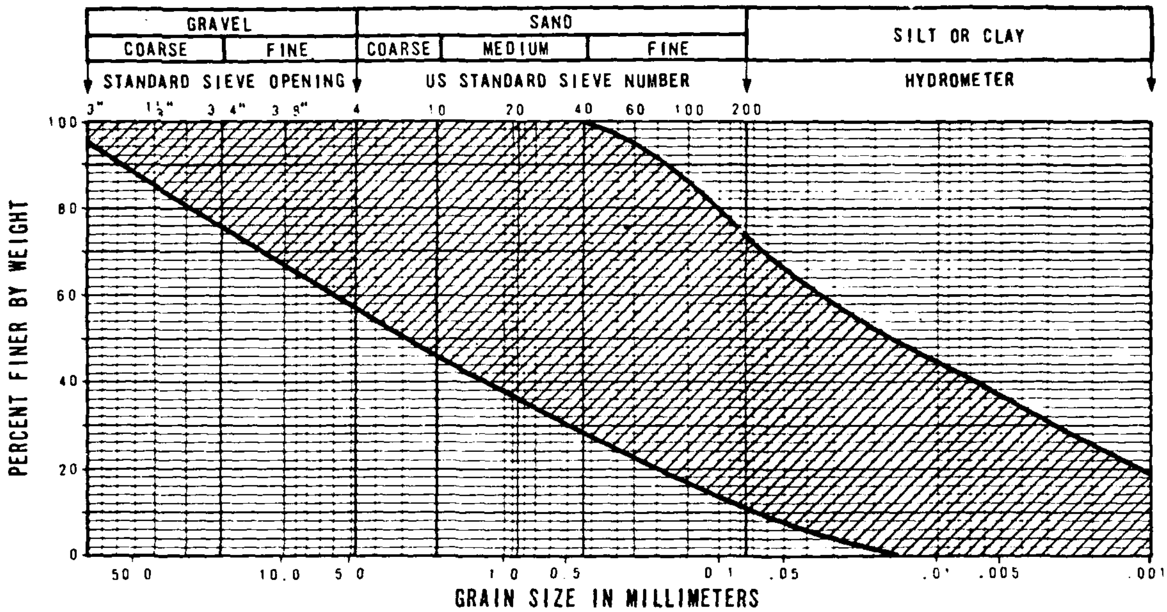
GEOLOGIC UNITS	
Ogallala formation (S5To)	
CL, SC, SM	
95-125 (1522- 2002)	
5-25	
30-100	
2.6-2.7	
Weak to very strong	
2700-10,000 (823-3048)	
001- 031	
0	
0-30	
0-40	
20-95	
10-75	
NP-45	
NP-20	
1±	
0.1± (Swell)	
2± (96±)	
.5-1.5 ksf (24-72 kN m^2), ϕ = 25°-35°	
4± (192±)	
115-125 (1842-2002)	
10-15	
5-40	

RANGE OF ENGINEERING AND GEOPHYSICAL PROPERTIES
MULESHOE, TEXAS

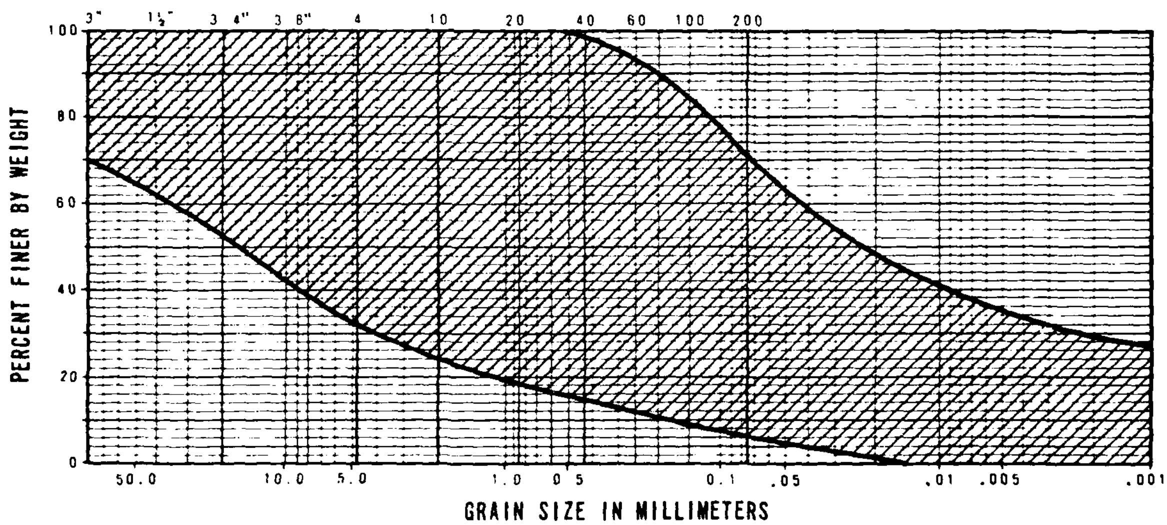
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

TABLE 3.8-3

FUGRO NATIONAL, INC.



S5To



A3s and A3d

RANGE OF GRADATION OF GEOLOGIC UNITS
MULESHOE, TEXAS
SOUTHERN HIGH PLAINS CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.8-7

FUGRO NATIONAL, INC.

Both the eolian deposits and the Ogallala Formation consist of mixtures of sandy clay and clayey to silty sand that are commonly cemented. These units are moderately compressible and have moderate shear strengths.

The presence of caliche in these units affects their engineering and geophysical characteristics. Chalky to strongly cemented caliche is present in both units. The Ogallala Formation also contains layers of massive, well-indurated caprock.

3.8.4 Conclusions

The following favorable and unfavorable geotechnical conditions for deployment of the MX system at the Muleshoe Site have been identified based on the results of the Characterization study.

Favorable conditions:

- Surface slopes are generally less than three percent and little preconstruction grading will be necessary.

- Drainages may be up to 30 feet deep (9 m) but are widely spaced; relatively few major drainage structures will be needed.

- An extensive network of paved and unpaved federal, state, and county roads traverse the site, minimizing the need for new roads.

- Most of the surficial soils have good subgrade characteristics for support of new roads.

- Except for the caliche, subsurface soils are generally suited for excavation by an MX trencher and conventional excavations required for the horizontal shelter. These soils are suitable for use as backfill.
- Sufficient quantities of fine aggregate for concrete and road construction are available in the vicinity of the site.
- Adequate quantities of water are available from existing wells.

Unfavorable conditions:

- The average depth to bedrock in the northern 60 percent of the site is 100 feet (30 m). Strong to very strongly cemented caliche is present within the construction zone in most of the subsurface.
- The average depth to ground water is 100 feet (30 m).
- Many trench and horizontal shelter excavations will encounter layers of well-cemented caliche requiring ripping or blasting.
- Most vertical shelter excavations will encounter ground water, caliche, and/or bedrock resulting in additional cost.
- Sufficient quantities of coarse aggregate for concrete and road construction are not available and will have to be hauled from distances greater than 50 miles (80 km).

o Most of the land is privately owned.

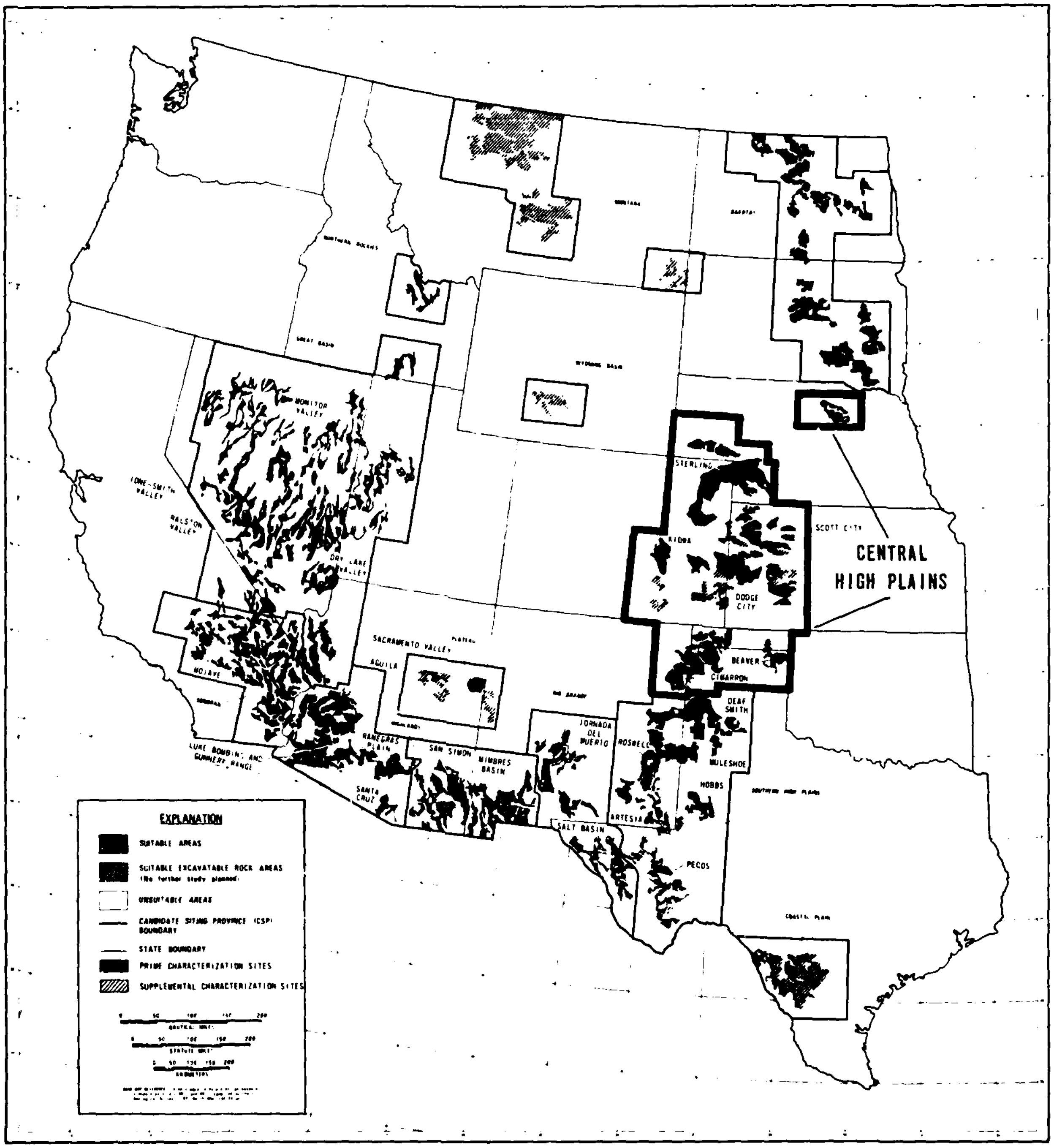
Overall, the geotechnical conditions at the Muleshoe Site are favorable for deployment of the present MX basing mode concepts.

3.9 SCOTT CITY: CENTRAL HIGH PLAINS CSP

The Central High Plains CSP lies within the Great Plains physiographic province and covers portions of Nebraska, Colorado, Kansas, Oklahoma, Texas and New Mexico (Figure 3.9-1). It is separated from the Southern High Plains by the Canadian River in northern Texas. Approximately 93 percent of the suitable area is privately owned and is used for farming (57%) and rangeland (36%). The remaining seven percent is state owned.

The CSP is characterized by exceptionally flat plains, broad river valleys, and low rolling hills. Six sites were selected to characterize geotechnical conditions in the CSP (Figure 3.9-2) based upon a review of regional information. The Scott City site is representative of geotechnical conditions in the eastern one-third of the CSP.

The Scott City site is 390 nm^2 (1338 km^2) in area, and is situated in Thomas and Logan Counties in northwestern Kansas (Figure 3.9-2). The site occupies a portion of an immense loess (eolian silt) plain with broad interstream divides, low relief and small, shallow closed playa basins. Field activities and their locations are identified in Figure 3.9-3. The scope of both the field and laboratory activities is presented in Table 3.9-1.

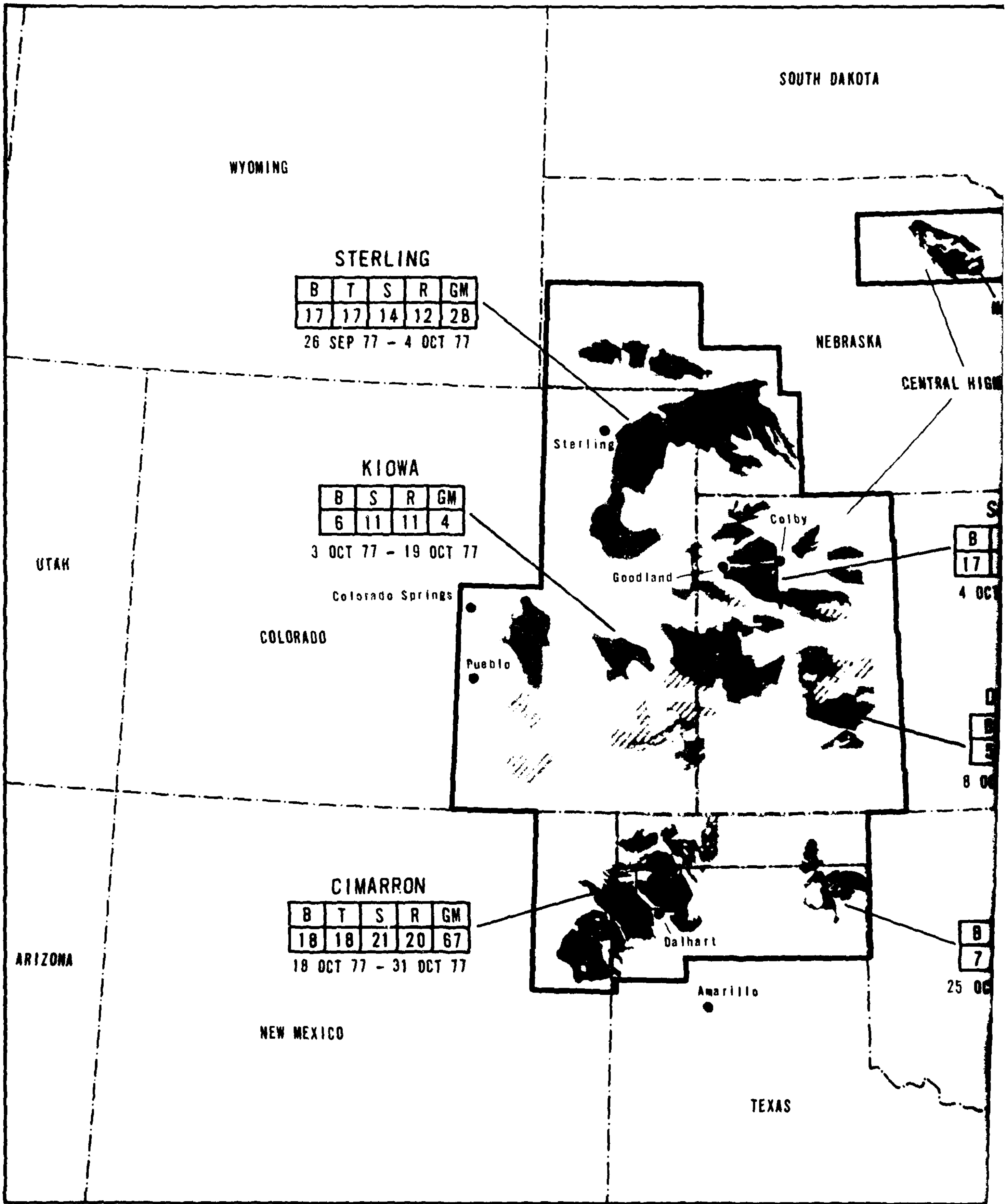


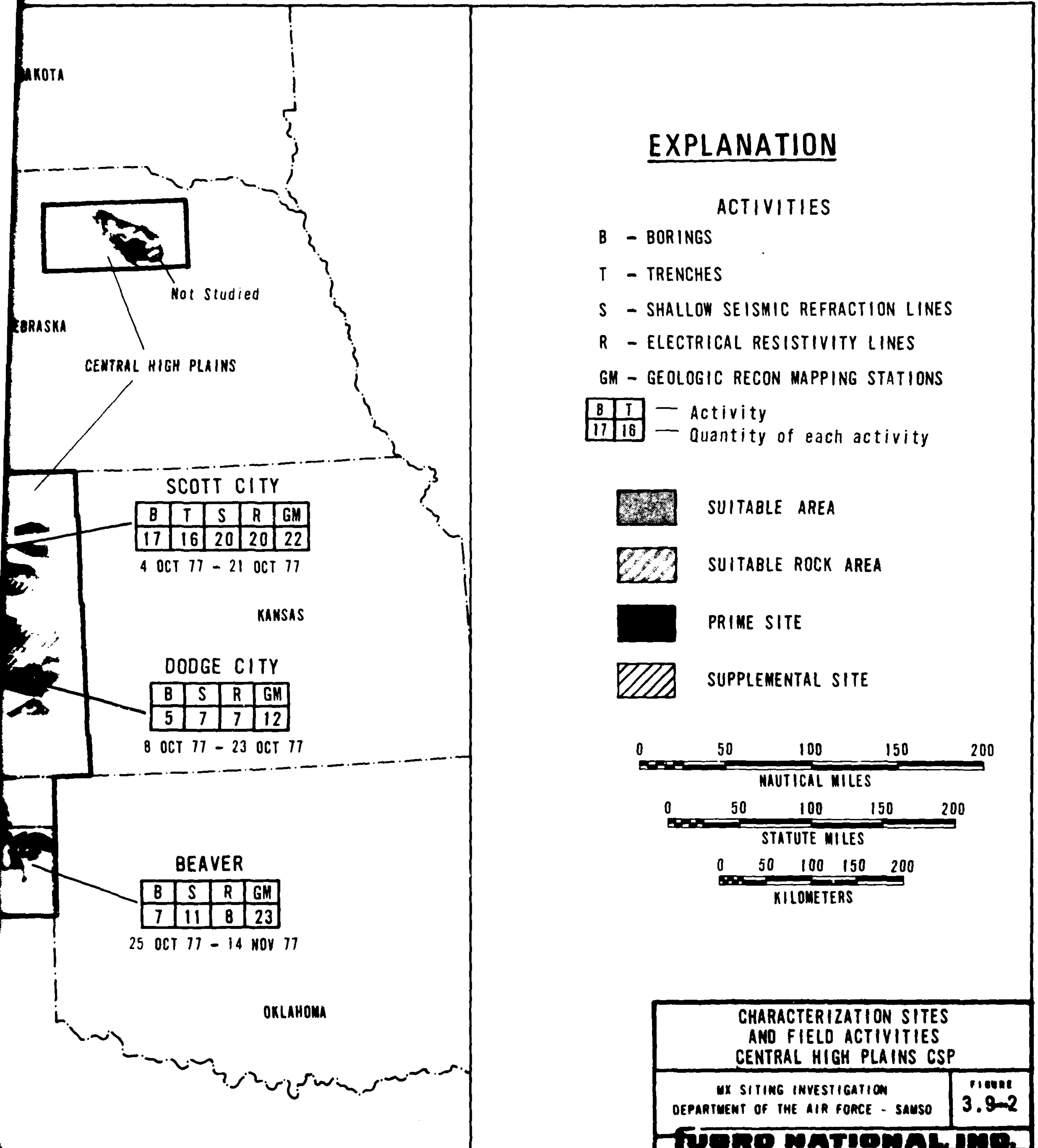
LOCATION OF CENTRAL HIGH PLAINS CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.9-1

FUGRO NATIONAL, INC.


SOUTH DAKOTA
WYOMING
STERLING
B T S R GM
17 17 14 12 28
26 SEP 77 - 4 OCT 77
NEBRASKA
CENTRAL HIG
Sterling
KIOWA
B S R GM
6 11 11 4
3 OCT 77 - 19 OCT 77
Colby
Goodland
UTAH
Colorado Springs
COLORADO
Pueblo
CIMARRON
B T S R GM
18 18 21 20 67
18 OCT 77 - 31 OCT 77
Dalhart
ARIZONA
Amarillo
NEW MEXICO
TEXAS

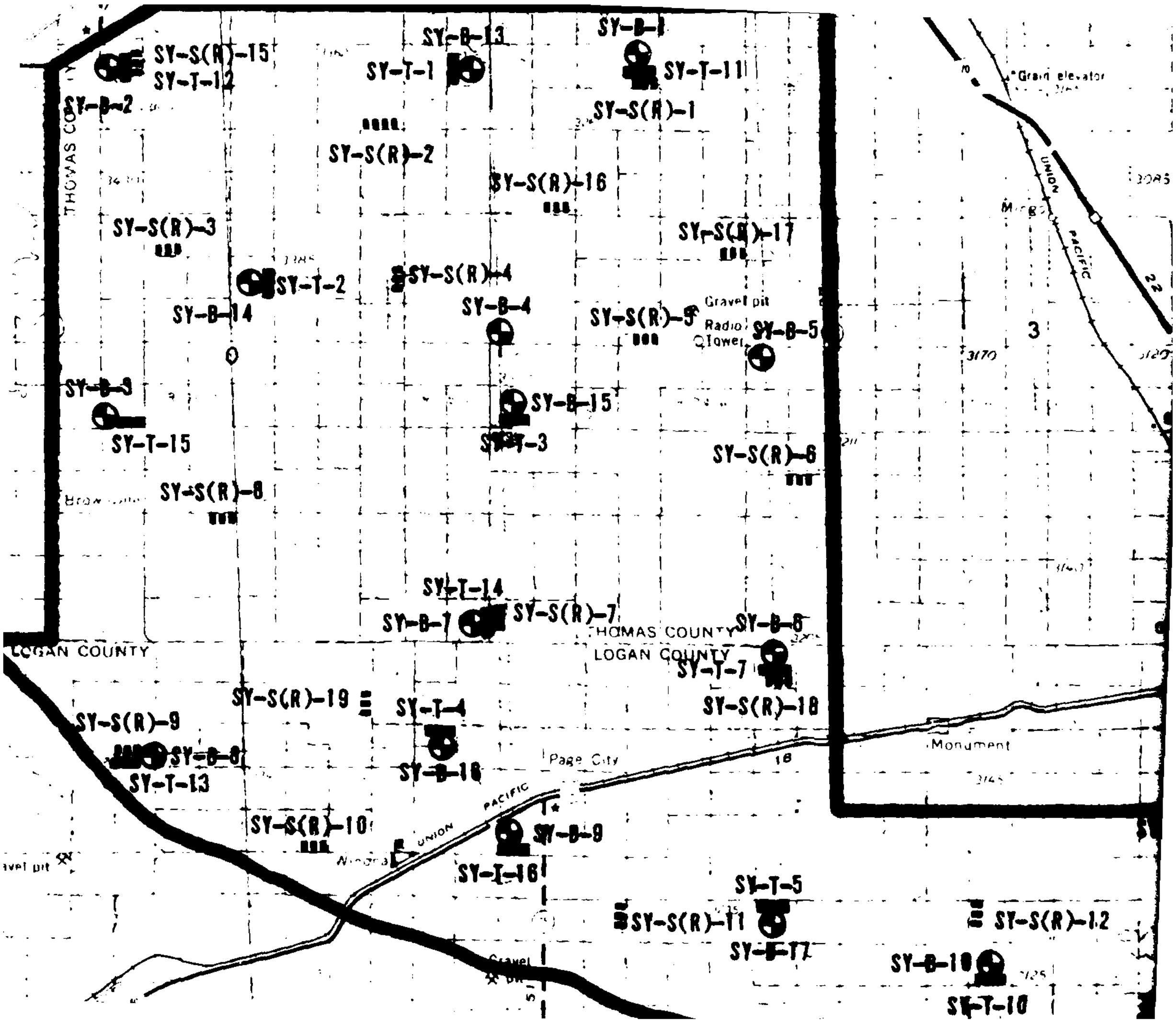


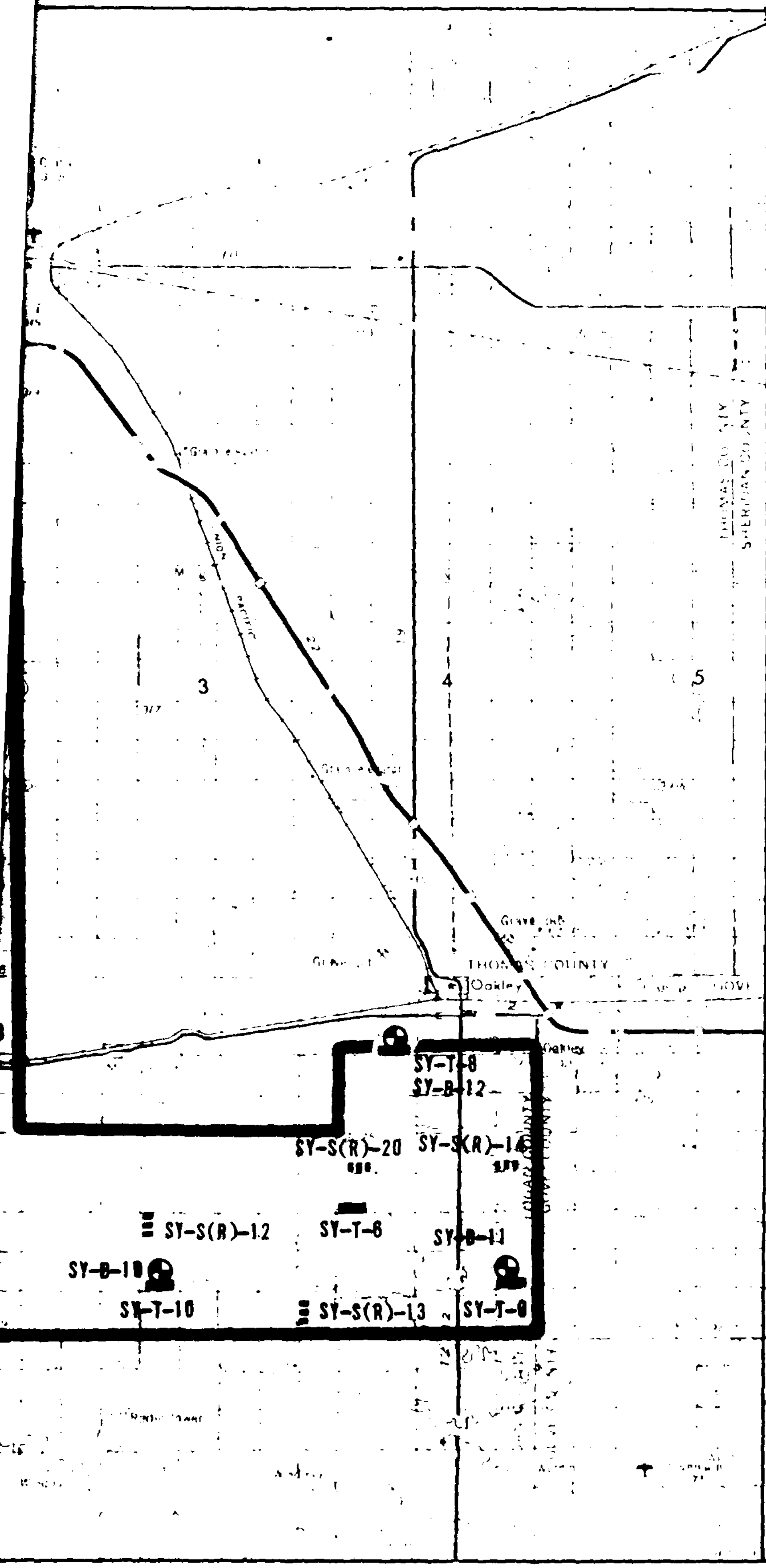
CHARACTERIZATION SITES
AND FIELD ACTIVITIES
CENTRAL HIGH PLAINS CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.9-2

FUGRO NATIONAL, INC.

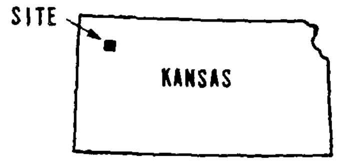

SY-S(R)-15
SY-T-12
SY-B-2
SY-B-13
SY-T-1
SY-T-11
SY-S(R)-1
SY-S(R)-2
SY-S(R)-16
THOMAS CO
SY-S(R)-3
SY-S(R)-17
SY-T-2
SY-S(R)-4
SY-B-4
SY-B-14
SY-S(R)-5
Gravel pit
Radio
Tower
SY-B-5
SY-B-3
SY-B-15
SY-T-15
SY-T-3
SY-S(R)-6
SY-S(R)-8
SY-T-14
SY-B-7
SY-S(R)-7
THOMAS COUNTY
LOGAN COUNTY
SY-B-6
SY-T-7
SY-S(R)-18
SY-S(R)-19
SY-T-4
SY-S(R)-9
SY-B-8
SY-T-13
SY-B-16
Page City
UNION PACIFIC
Monument
SY-S(R)-10
SY-B-9
SY-T-16
SY-T-5
SY-S(R)-11
SY-S(R)-12
SY-B-10
SY-T-10
Gravel pit
Grain elevator
3
22
3085
3170



EXPLANATION

- Boring
- Seismic refraction (S) and resistivity (R) lines
- Trench

SITE LOCATION



1:250,000

1" = 3.2 Nautical Miles (APPROXIMATE)

ACTIVITY LOCATION MAP
SCOTT CITY, KANSAS
CENTRAL HIGH PLAINS CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.9-3

FUGRO NATIONAL, INC.

GEOLOGY AND GEOPHYSICS

TYPE OF ACTIVITY	NUMBER OF ACTIVITIES
Geological mapping stations	22
Shallow refraction	20
Electrical resistivity	20

ENGINEERING

NUMBER OF BORINGS	DEPTH FEET(METERS)
12	50 (15)
4	100 (30)
1	300 (91)

NUMBER OF TRENCHES	DEPTH FEET(METERS)
16	10-15 (3-5)

ENGINEERING-LABORATORY TESTS

TYPE OF TEST	NUMBER OF TESTS
Moisture/density	167
Specific gravity	6
Sieve analysis	37
Hydrometer	18
Atterberg limits	27
Consolidation	2

TYPE OF TEST	NUMBER OF TESTS
Unconfined compression	6
Triaxial compression	5
Direct shear	5
Compaction	2
CBR	2
Chemical analysis	2

SCOPE OF FIELD AND LABORATORY ACTIVITIES
SCOTT CITY, KANSAS

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE 3.9-1

FUGRO NATIONAL, INC.

3.9.1 Surficial Geology and Terrain

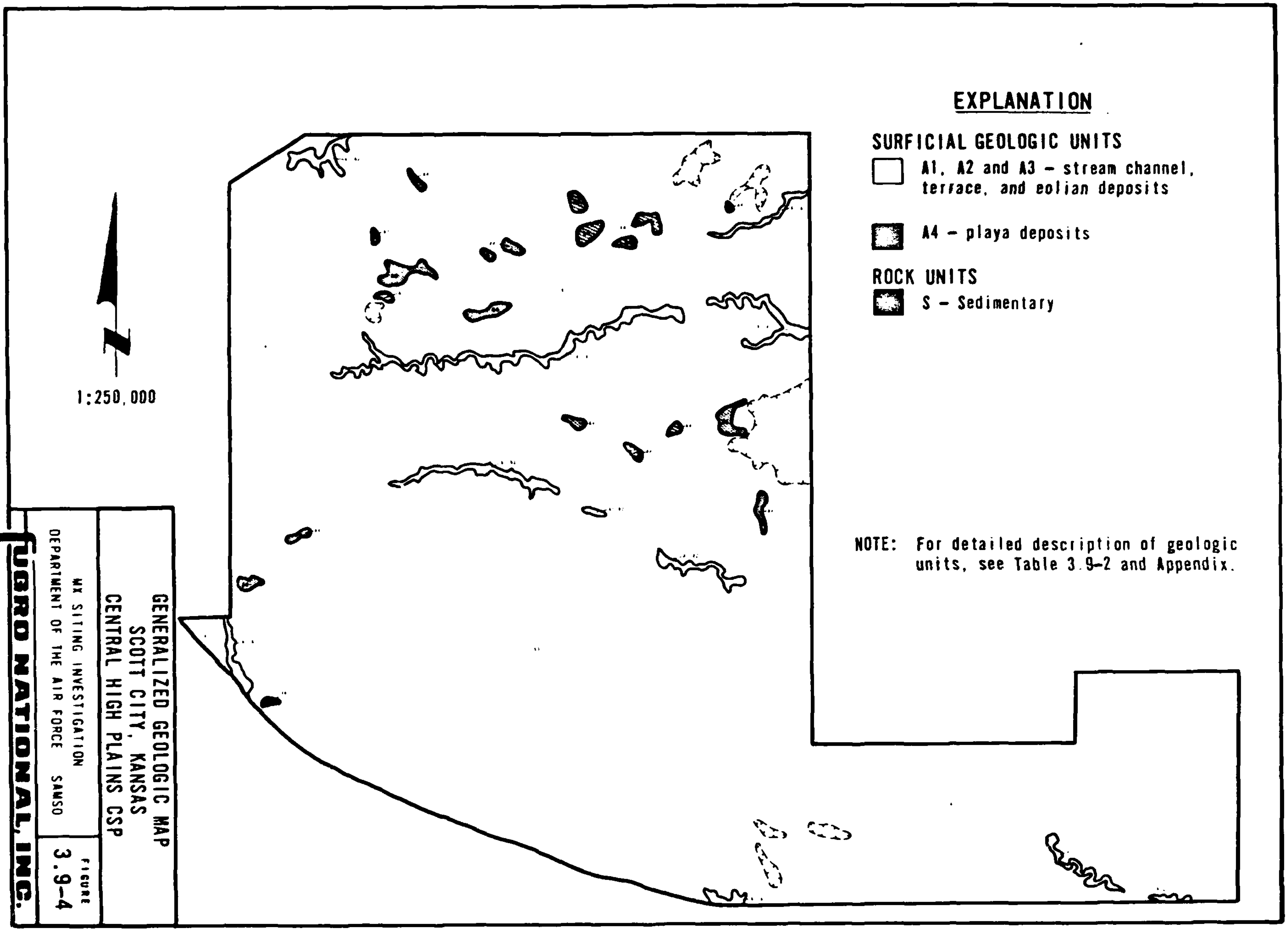
The distribution of surficial geologic units at the Scott City site is presented in Figure 3.9-4, and their characteristics are presented in Table 3.9-2.

Loess (eolian silt) is the predominant surficial geologic unit covering approximately 90 percent of the site. Fluvial, stream terrace, and playa deposits cover most of the remaining ten percent and generally overlie the loess deposits. The fluvial and stream terrace deposits range from gravelly sand to silty clay while the playa deposits are primarily composed of plastic clays. Other surficial geologic units at the site include the Ogallala Formation, Pierre Shale, and soil deposits (undifferentiated).

The site slopes gently to the east at a gradient of 0.3 percent. Local relief generally does not exceed a few tens of feet and the predominant surficial deposit (loess) forms zero to three percent slopes. Drainage channels are typically 20 to 30 feet (6 to 9 m) deep and 0.4 nm (1.3 km) wide, with banks of 3 to 18 percent slope.

3.9.2 Subsurface Conditions

A profile of the soils encountered in the borings and trenches is shown in Figure 3.9-5. The surficial loess deposits, indicated as CL and ML in the figure, extend to an average depth of 35 feet (11 m). They are underlain by the Ogallala Formation which is indicated mostly as SM, SP and SC in Figure



GENERALIZED GEOLOGIC MAP
SCOTT CITY, KANSAS
CENTRAL HIGH PLAINS CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE 3.9-4

FUGRO NATIONAL, INC.

ENGINEERING GEOLOGY UNIT (c)	GEOLOGIC AGE	THICKNESS FEET (METERS) (a)	DESCRIPTIVE NAME(S)	USCS SYMBOL(S)	AREAL EXTENT (SITE	
					nm^2 (km^2)	PERCEN
Undifferentiated Non-Rock Deposits (Au)	Quaternary	15-25 (5-8)	Silty Clay	CL	< 1	< 1
Aluvial Deposits (A1)	Quaternary	20-30 (6-9)	Gravelly Sand to Silty Clay	SW to CL	8 (27)	2
Stream Terrace Deposits (A2)	Quaternary	20-30 (6-9)	Gravelly Sand to Silty Clay	SW to CL	4 (14)	1
Eolian Deposits, Silt (Loess)(A3L)	Pleistocene	30-40 (9-12)	Clayey Silt	ML	371 (1273)	95
Playa Deposits (A4)	Quaternary	5-15 (2-5)	Silty Clay	CL, CH	8 (27)	2
Ogallala Formation (S5To)	Pliocene	90-110 (27-34)	Clayey Silt to Gravel	ML to GP	< 1	< 1
Pierre Shale (S3kp)	Cretaceous	600-800 (183-244)	Shale	CH-OH	< 1	< 1

NOTES:

(a) Thickness range represents the most common occurrence.

(b) Excavatable rock.

(c) For generic description of geologic units, see Appendix.

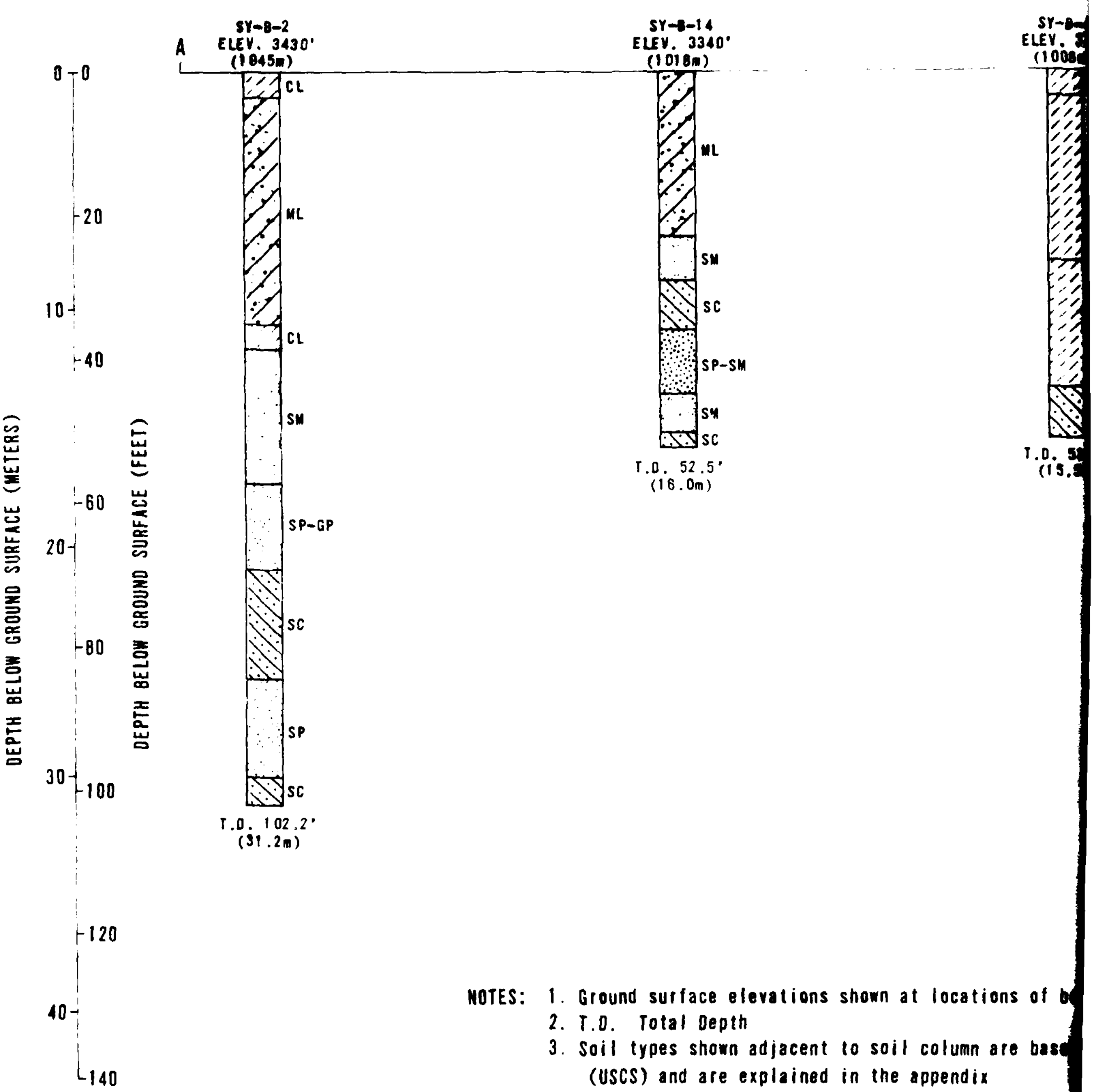
AREAL EXTENT (SITE)		PROPERTIES OF SURFACE MATERIALS					SURFACE MORPHOLOGY		NOTES
mi^2 (km^2)	PERCENT	GRADATION	CEMENTATION	MAXIMUM GRAIN SIZE	PAVEMENT/ PATINA	STAGE OF CALICHE	SLOPE (PERCENT)	DRAINAGE DEPTHS FEET(METERS)	
< 1	< 1	Poor	None-Weak	Sand	Not Applicable	None-I	3-15	20-30 (6-9)	
8 (27)	2	Poor-Well	None-Weak	Gravel	Not Applicable	None-I	1-5	20-30 (6-9)	
4 (14)	1	Poor-Well	None-Weak	Gravel	Not Applicable	None-I	1-5	20-30 (6-9)	
371 (1273)	95	Poor	None-Weak	Sand	Not Applicable	None-I	0-3	20-30 (6-9)	
8 (27)	2	Poor	None	Silt	Not Applicable	None	0-1	None	
< 1	< 1	Poor-Well	Weak-Strong	Cobble	Not Applicable	I-IV	0-4	None	
< 1	< 1	Poor	—	Sand	Not Applicable	—	6-25	None	(b)

DESCRIPTION OF SURFICIAL GEOLOGIC UNITS
SCOTT CITY, KANSAS

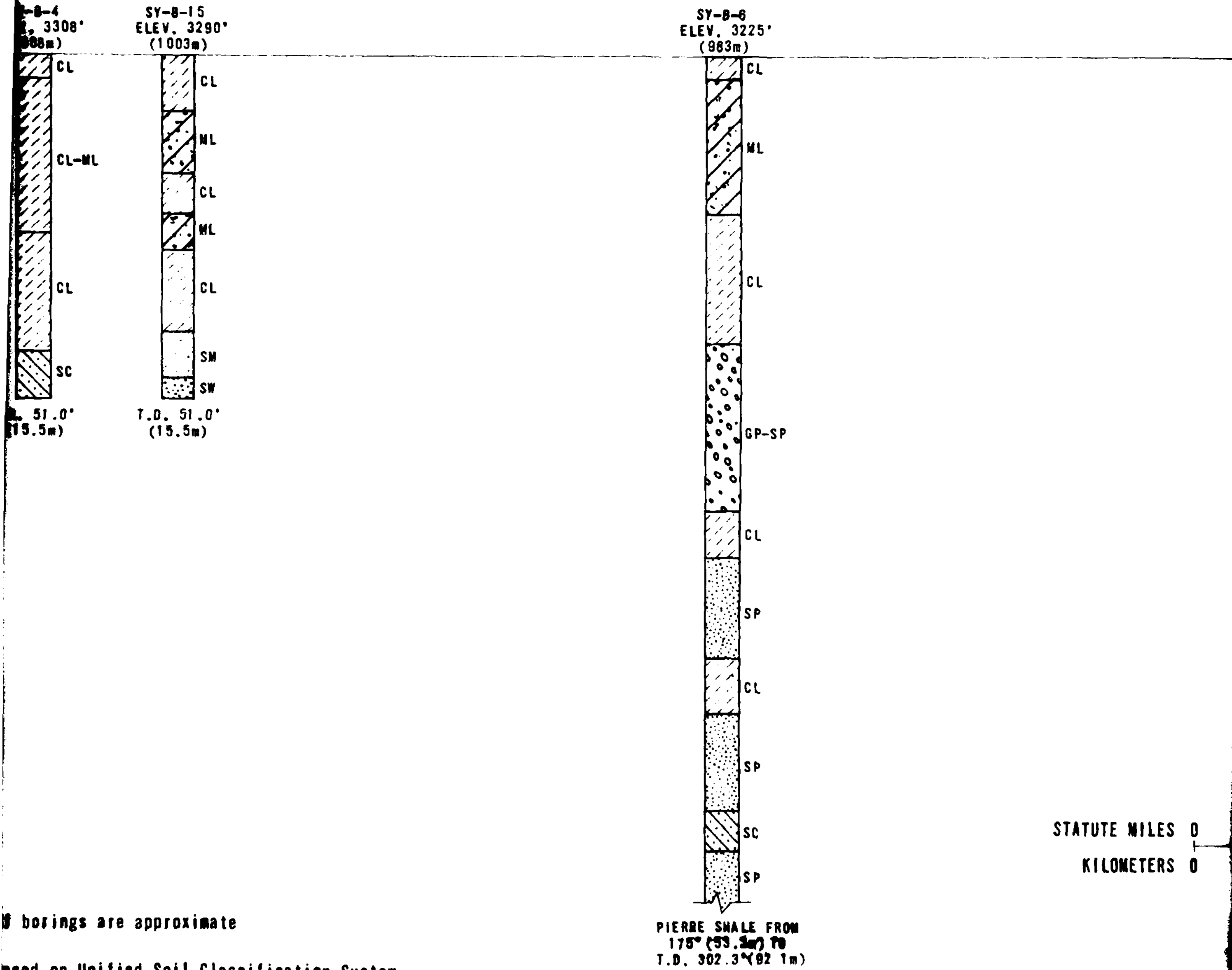
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

TABLE 3.9-2

FUGRO NATIONAL, INC.

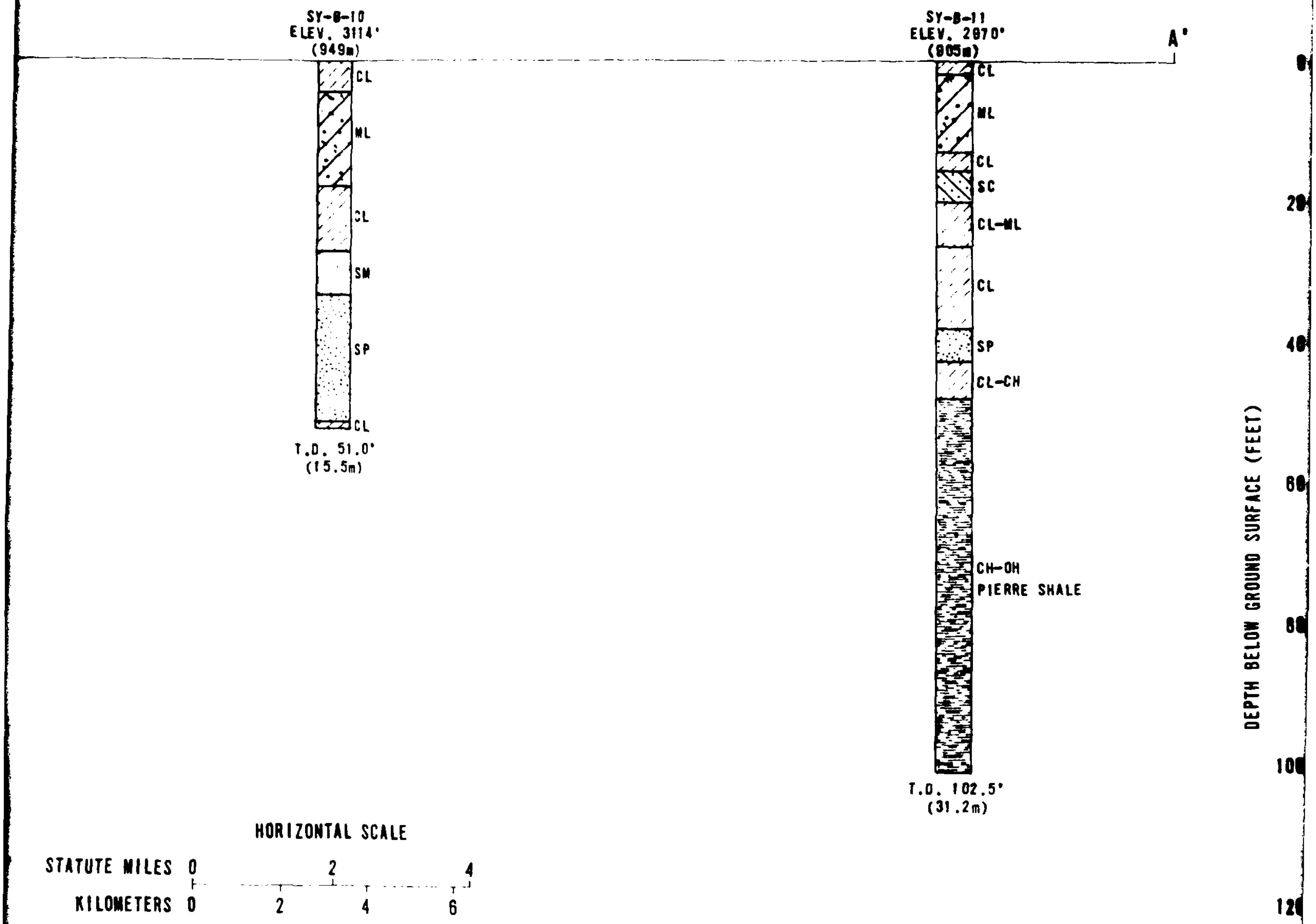


NOTES: 1. Ground surface elevations shown at locations of b
2. T.D. Total Depth
3. Soil types shown adjacent to soil column are bas
(USCS) and are explained in the appendix

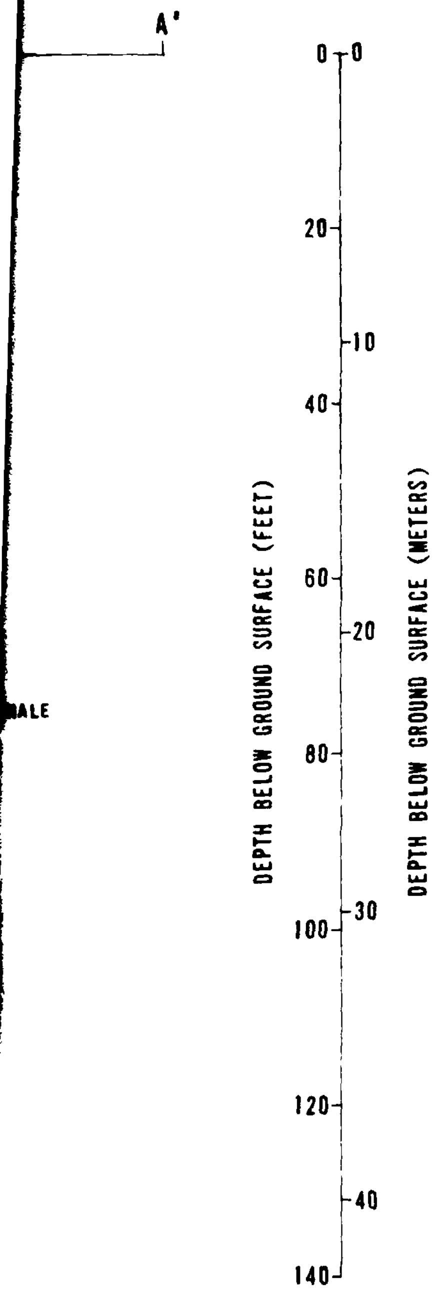


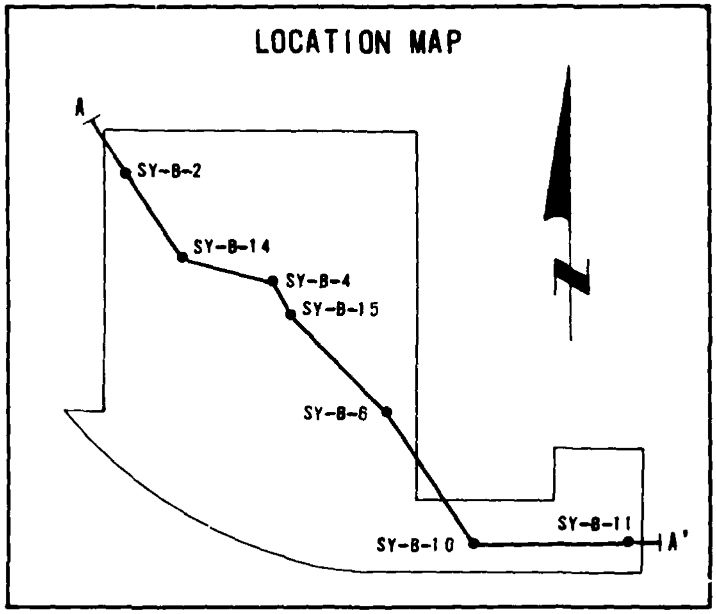
borings are approximate

ased on Unified Soil Classification System



SY-B-10
ELEV. 3114'
(949m)
CL
ML
CL
SM
SP
CL
T.D. 51.0'
(15.5m)
SY-B-11
ELEV. 2970'
(905m)
A'
CL
ML
CL
SC
CL-ML
CL
SP
CL-CH
CH-OH
PIERRE SHALE
T.D. 102.5'
(31.2m)
HORIZONTAL SCALE
STATUTE MILES 0 2 4
KILOMETERS 0 2 4 6
DEPTH BELOW GROUND SURFACE (FEET)
20
40
60
80
100
120





SOIL PROFILE
SCOTT CITY, KANSAS
CENTRAL HIGH PLAINS CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE
3.9-5

FUGRO NATIONAL, INC.

3.9-5. The Ogallala Formation is unconformably underlain by Pierre Shale (Figure 3.9-6), which occurs at an average depth of 145 feet (44 m). The Pierre Shale is believed to be the 7000 fps (2134 mps) seismic velocity refractor and is classified as "excavatable" rock. It is approximatly 700 feet (213 m) thick and is underlain by over 2000 feet (610 m) of Mesozoic shale, limestone, and sandstone.

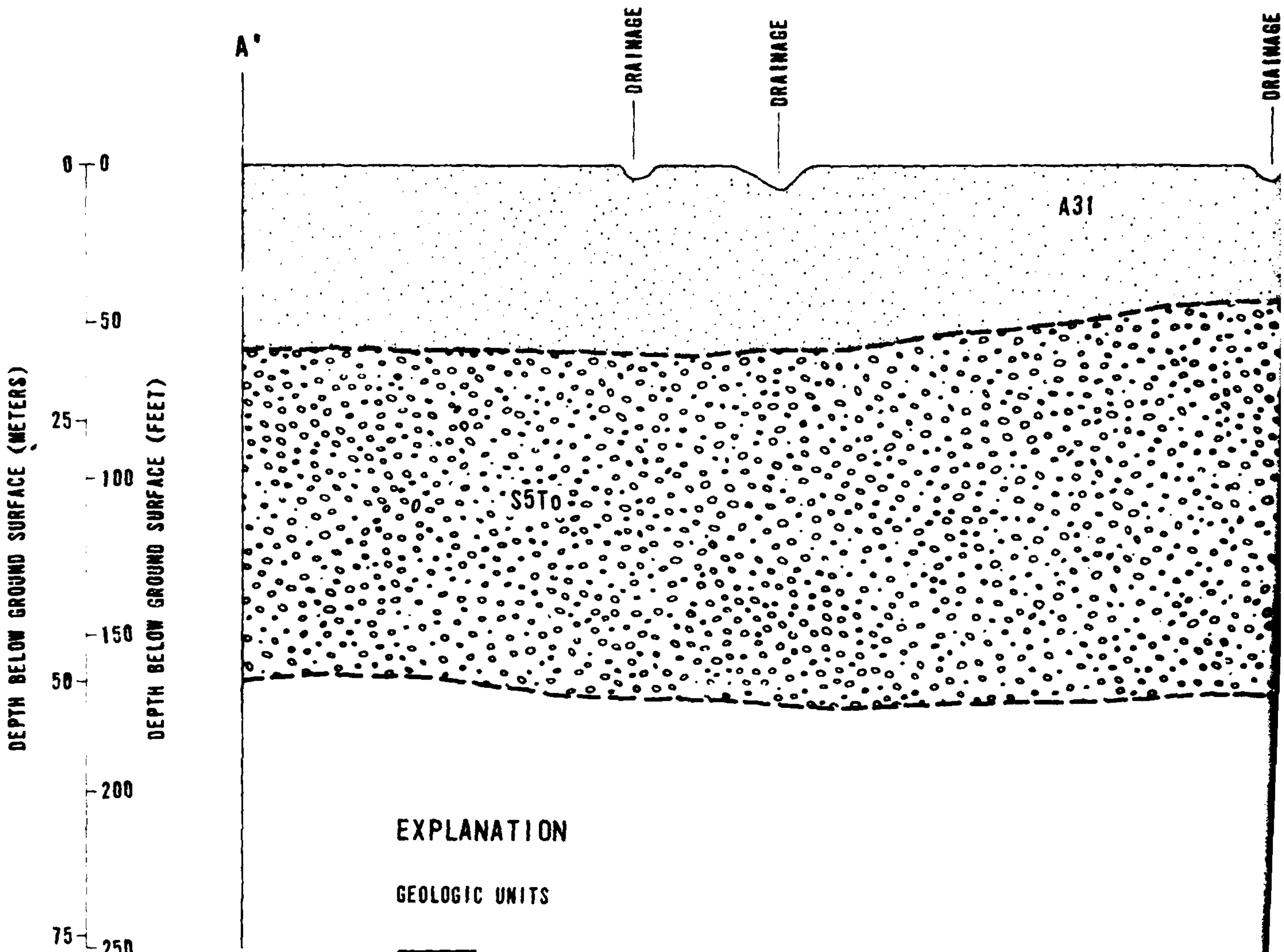
The principal aquifer in the site area is the Ogallala Formation. Published data indicate that the ground-water table ranges from approximately 65 feet to 190 feet (20 m to 58 m).

3.9.3 Engineering and Geophysical Properties

Engineering and geophysical properties of the predominant geologic units at the Scott City site are summarized in Table 3.9-3 and Figure 3.9-7.

The loess deposits are primarily formed of uncemented unsaturated poorly graded and slightly plastic clayey silt. They have a moderately high shear strength, are moderately compressible, and are subject to limited structural collapse upon wetting.

The Ogallala Formation is generally formed of uncemented, mostly unsaturated and well graded silty and clayey sands with varying amounts of gravel and local caliche caprock. It has high shear strength and low compressibility.



EXPLANATION

GEOLOGIC UNITS

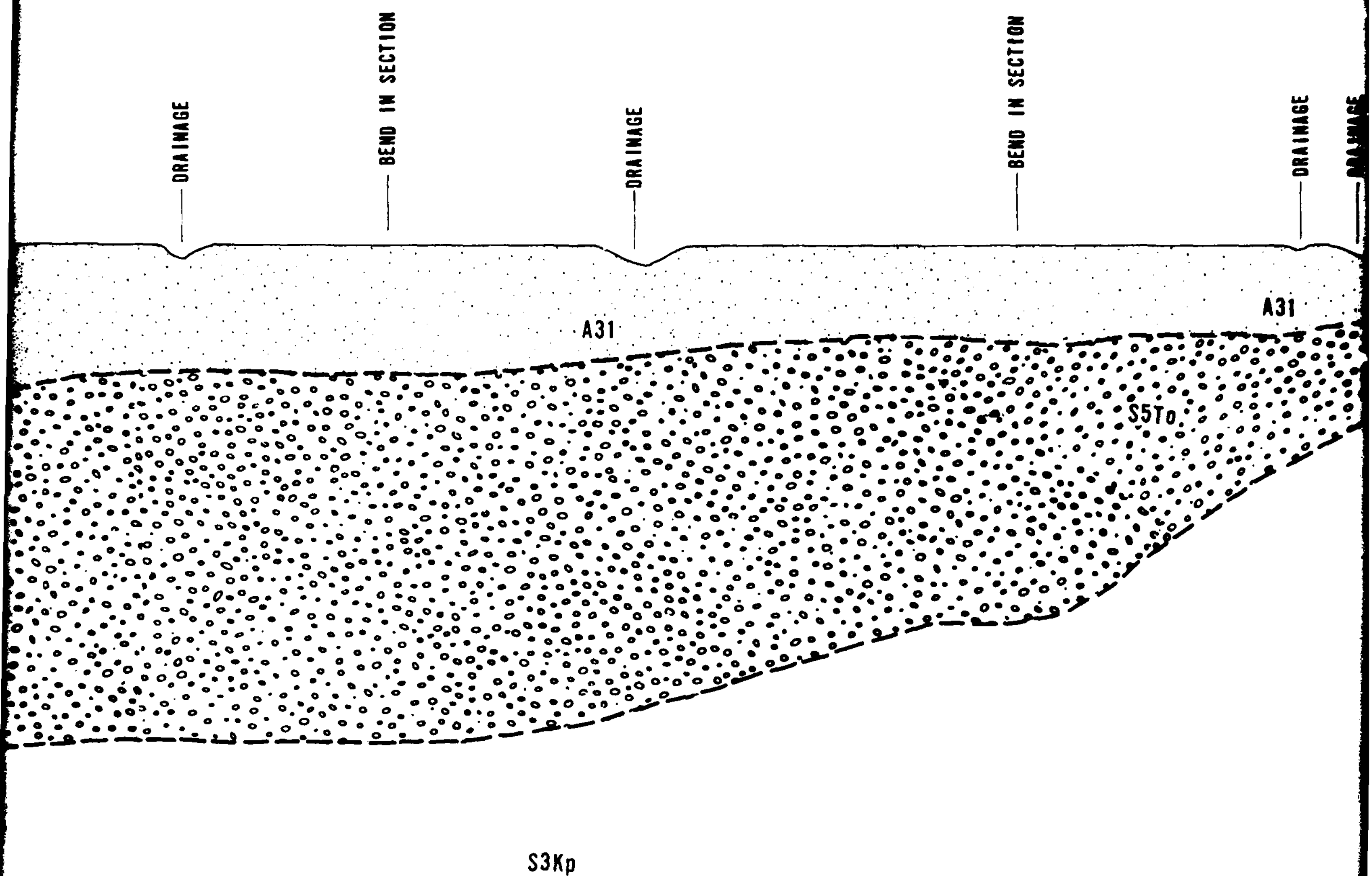
A31 — Loess; Eolian silt deposits; average seismic velocity 1100–1300 fps

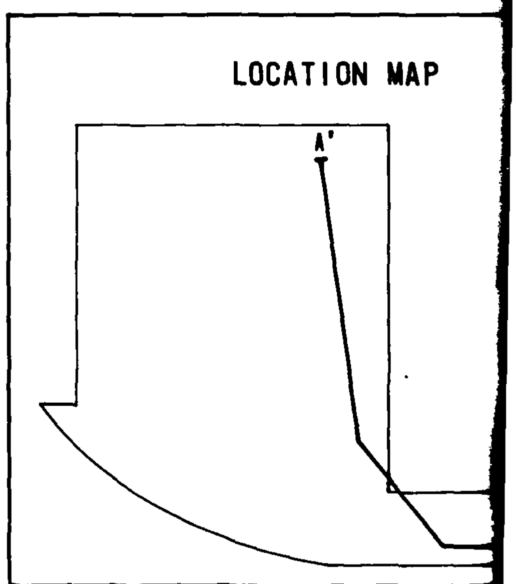
S5To — Ogallala Formation; Unconsolidated sand, silt, gravel, cobbles or cl
caliche caprock; average seismic velocity 1700–5000 fps (518–1524 m

S3Kp — Pierre Shale; Excavatable, fissile shale with thin bentonite interbe
seismic velocity >7000 fps (2134 mps).

SYMBOLS

– – – – Approximate Geologic Contact



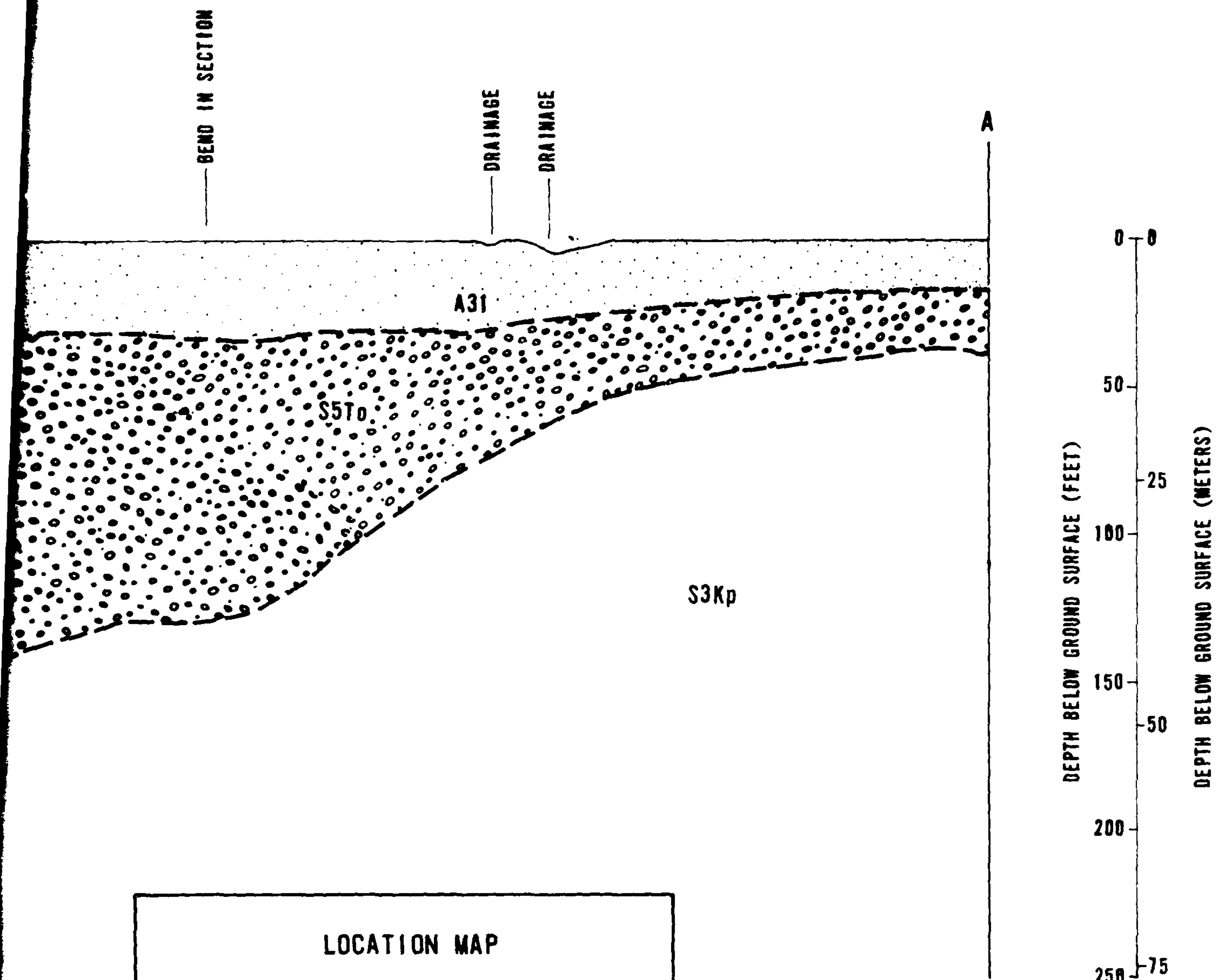


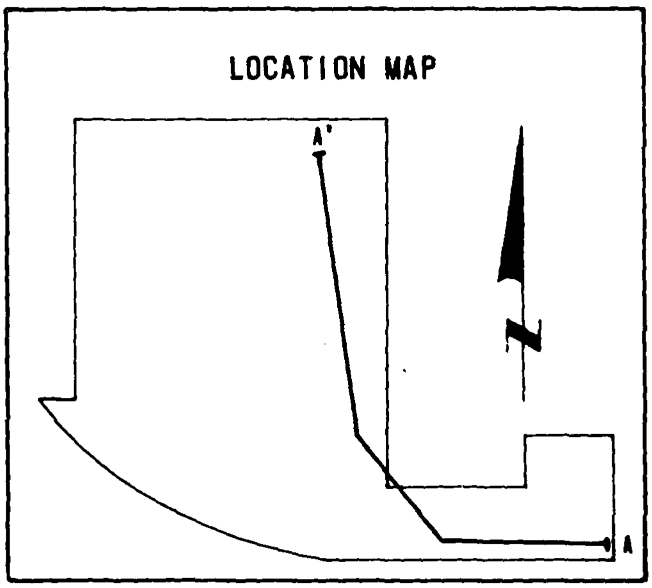
ly 1100–1300 fps (335–396 mps).

, cobbles or clay with local
fps (518–1524 mps).

ntonite interbeds; average

NOTE: Approximately 3000' (914m) of Mesozoic shale, limestone and sandstone underlie the Ogallala Formation (S5To)





esozoic
underlie

HORIZONTAL SCALE: 1" ≈ 2 MILES (3km)
VERTICAL SCALE: 1" = 50' (15m)
VERTICAL EXAGGERATION: 211X

GENERALIZED GEOLOGIC CROSS SECTION
SCOTT CITY, KANSAS
CENTRAL HIGH PLAINS CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.9-6

FUGRO NATIONAL, INC.

ENGINEERING AND GEOPHYSICAL PROPERTIES	Eolian loess deposits (A31)	Ogallala formation (S5T
UNIFIED SOIL CLASSIFICATION SYMBOL(S)	ML, CL-ML, CL	SP, SW, SW-SM, SC, GW, GP,
GENERAL PROPERTIES		
DRY DENSITY pcf(kg m^3)	70-115 (1121-1842)	98-127 (1570-2034)
MOISTURE CONTENT (%)	8-25	2-17
DEGREE OF SATURATION (%)	20-97	9-97
SPECIFIC GRAVITY	2.65	2.67
DEGREE OF CEMENTATION	None to weak	Weak to strong
COMPRESSIONAL WAVE VELOCITIES fps(mps)	1000-1300 (305-396)	1700± (518±)
ELECTRICAL CONDUCTIVITY (mhos m)	.018-.053	.004-.023
GRAIN SIZE DISTRIBUTION (%)		
BOULDERS >12 inches(30cm)	0	0
COBBLES 3 to 12 inches(8to 30cm)	0	0-5
GRAVEL	0	0-25
SAND	0-5	10-96
SILT AND CLAY	95-100	5-90
PLASTICITY DATA		
LIQUID LIMIT	27-47	DNA
PLASTICITY INDEX	2-24	DNA
COMPRESSIBILITY DATA		
COMPRESSION AT 4 ksf(192kN/m^2) (%)	2-6	DNA
SWELL OR COLLAPSE UPON SATURATION (%)	0 - 3' (Collapse)	DNA
SHEAR STRENGTH DATA		
UNCONFINED COMPRESSION ksf(kN m^2)	0.3-5 (14-239)	DNA
CD TRIAXIAL COMPRESSION	c=0-0.7 ksf (34 kN m^2), ϕ=26°-33°	DNA
DIRECT SHEAR ksf(kN m^2)	0.7-5 (34-240)	DNA
COMPACTION AND CBR DATA		
MAXIMUM DRY DENSITY pcf(kg m^3)	110-115 (1762-1842)	DNA
OPTIMUM MOISTURE CONTENT (%)	14-17	DNA
CBR AT 90% RELATIVE COMPACTION	4-6	DNA

DNA = DATA NOT AVAILABLE (INSUFFICIENT DATA OR TESTS NOT PERFORMED)

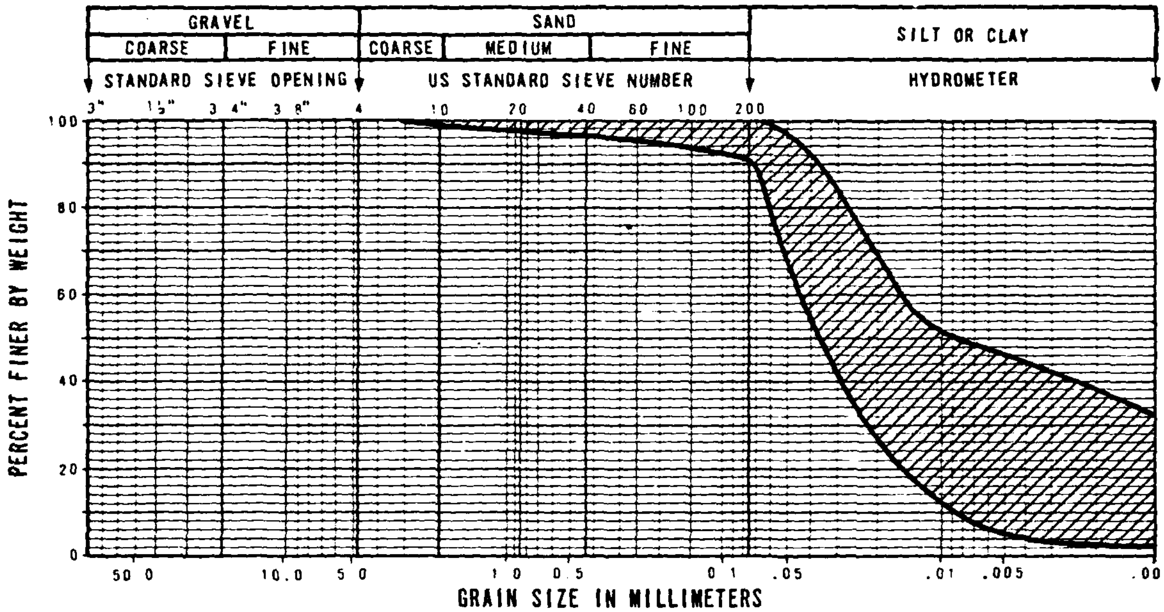
GEOLOGIC UNITS	
Ogallala formation (S5To)	
[illegible]P, SW, SW-SM, SC, GW, GP, ML	
98-127 (1570-2034)	
2-17	
9-97	
2.67	
Weak to strong	
1700± (518±)	
.004-.023	
0	
0-5	
0-25	
10-96	
5-90	
DNA	
DNA	
DNA	
DNA	
DNA	
DNA	
DNA	
DNA	
DNA	
DNA	

RANGE OF ENGINEERING AND GEOPHYSICAL PROPERTIES
SCOTT CITY, KANSAS

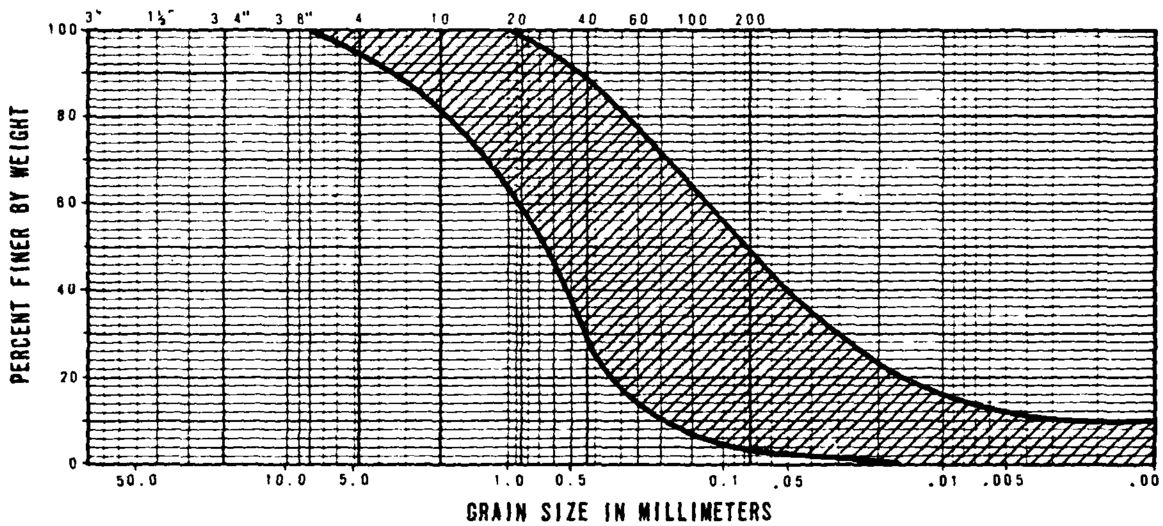
MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

TABLE 3.9-3

FUGRO NATIONAL, INC.



A3I



S5To

RANGE OF GRADATION OF GEOLOGIC UNITS
SCOTT CITY, KANSAS
CENTRAL HIGH PLAINS CSP

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 3.9-7

FUGRO NATIONAL, INC.

3.9.4 Conclusions

Based on the results of the characterization study, a list of both favorable and unfavorable geotechnical conditions for deployment of the MX system at Scott City is presented below.

Favorable conditions:

- o Surface slope is generally less than 0.3 percent requiring little preconstruction grading.

- o A network of unpaved farm roads exists over approximately 80 percent of the site area, minimizing the need for new road construction.

- o Soils are well suited for: excavation of vertical shelters using augers, continuous excavations by an MX trencher, and conventional excavations for horizontal shelters.

- o Engineering characteristics of the soils are relatively uniform and predictable.

- o Depth to rock exceeds 120 ft (37 m) over more than 95 percent of the area.

- o Ground water ranges in depth from 65 to 190 ft (20 to 58 m) and will not be encountered in most excavations.

Unfavorable conditions:

- o Surficial soils have poor support characteristics for use as road subgrade.

- o Coarse aggregate will have to be imported and haul distances will exceed 60 miles (96 km).
- o Compaction of site soils is not feasible in wet or frozen conditions because of their fine-grained nature.
- o More than 90 percent of the site area is privately owned.

In summary, the Scott City site area is considered favorable for basing modes requiring shallow excavations because of the ease of excavation and adequate stability of the soils, allowing economical cast-in-place construction. The site area is considered unfavorable for the vertical shelter basing mode because the surficial soils have relatively low bearing strength, requiring thick roadway sections. To support the heavy wheel loads of the MX transporter, either base course material will have to be imported or soil improvement techniques will have to be used. Either procedure is expensive and road construction costs will be high.

4.0 CANDIDATE SITING REGIONS GEOTECHNICAL RANKING

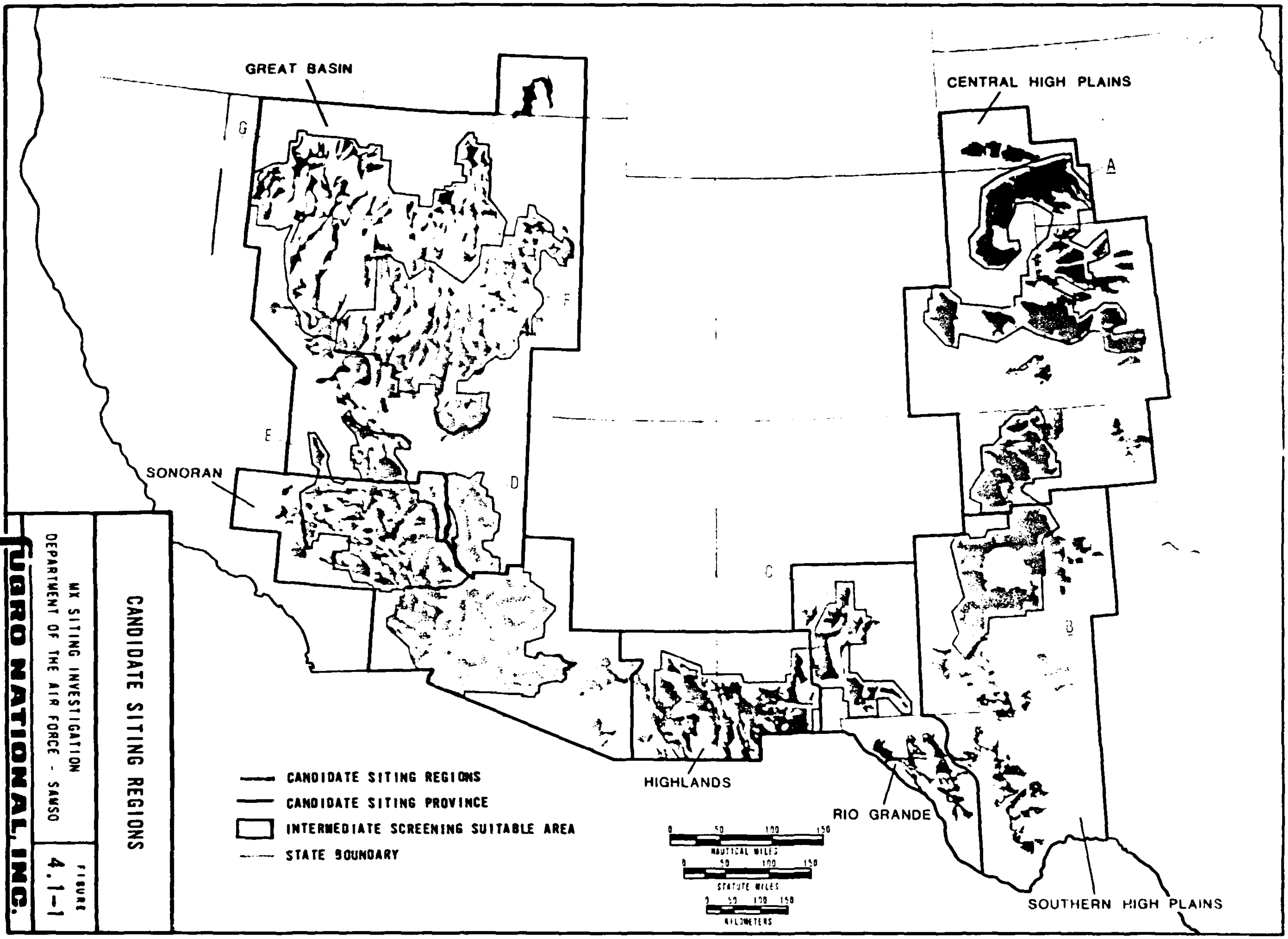
4.1 CANDIDATE SITING REGION SELECTION

After completion of Fine Screening, a total of 56,500 square nautical miles (194,000 km^2) were defined as suitable area for MX deployment in the six Candidate Siting Provinces. The suitable area in each CSP was greater than that required in a siting region, thus, it was necessary to go through the following selection process to define Candidate Siting Regions (CSRs):

- Aggregations of suitable area were delineated that were larger than 1,000 nm^2 (3,400 km^2) and not bisected by interstate and U.S. highways, major streams, or major culture features.
- The large aggregations were combined, based on close proximity to one another, to form the core of CSRs.
- Smaller aggregations of suitable land were added so that each CSR had the required total area.

Using this process, approximately 70 percent of the available suitable area defined by Fine Screening was included in the seven selected CSRs. The remaining 30 percent is still potentially suitable area will not be considered for siting unless additional area is required.

Note the relationship of the boundaries of the seven CSRs and the Candidate Siting Provinces as shown on Figure 4.1-1. For referencing, each CSR has been designated by a letter from



CANDIDATE SITING REGIONS

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 4.1-1

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A to G. The CSRs and associated suitable areas are as follows:

CSR	Suitable Area (nm^2)	Suitable Area (km^2)
A	7100	24,400
B	6030	20,700
C	6150	21,100
D	6890	23,700
E	6020	20,700
F	7630	26,200
G	7170	24,600

4.2 GEOTECHNICAL RANKING METHODOLOGY

4.2.1 Basing Modes and Excursions

Preliminary ranking of the hardened vertical shelter was started in March 1978, but not completed due to redirection to the hybrid trench concept in accordance with instructions by SAMSO. Preliminary geotechnical ranking has been completed for the vertical shelter (hardened) and hybrid trench (in-line) and will be started by 26 June for the horizontal shelter (loading dock).

The preliminary geotechnical ranking results are based on "baseline" or nominal costs and do not take into consideration the possible ranges in costs. A more detailed probability study is in progress and final ranking will be based on this more detailed study. It is possible that the ranking of the CSRs could change as a result of the more detailed study.

4.2.2 Procedure

A cost measure decision methodology is being used to rank the CSRs. In this process, costs are determined for construction activities and materials that are affected by geotechnical factors. The dollar base provides a means of integrating the many variables in a logical manner. It also allows flexibility in updating the ranking for new design concepts since most parameters remain as constants.

The first step in the ranking process is to list all the construction activities and materials which are affected by

geotechnical conditions using unit costs already developed by other contractors or developing our own unit costs. The variation in construction costs are determined for each item being considered. For example, an evaluation is made of interconnecting roads for the shelter concept. From the Characterization studies, general information about soil type, consistency and bearing strength is known. Using available design procedures, the required road section for different soil conditions is determined. The volume of each layer (i.e. surface layer, base, sub-base) is calculated and knowing the individual unit costs, the cost per lineal foot of road is calculated.

Because the conditions within each CSR are highly variable, each CSR is divided into smaller areas and into geologic units within each area. The costs are first determined for soil conditions typically associated with individual geologic units; knowing their approximate areal distribution and the percentage of CSR represented by each unit, it is possible to calculate the approximate cost of each item within the CSR. After determining the costs of each item for each CSR, the costs are totaled. The CSR with the lowest cost is ranked first in the cost measures methodology.

In this initial ranking, items have not been included which are not directly related to geotechnical factors. For example, material costs have not been considered, but could be if a more comprehensive, all encompassing ranking were carried out. It is recognized that steel costs, cement costs, or other material

costs do vary according to geographical location, but such variations have not been considered in the geotechnical ranking. Likewise, land costs, security fencing, and ordinance detection are not included. Weather is considered as a cost item because it does affect other construction items considered. Cost effects of adverse weather include lost time due to rain and snow, and decreased productivity due to very warm or very cold temperatures.

4.3 HARD VERTICAL SHELTER

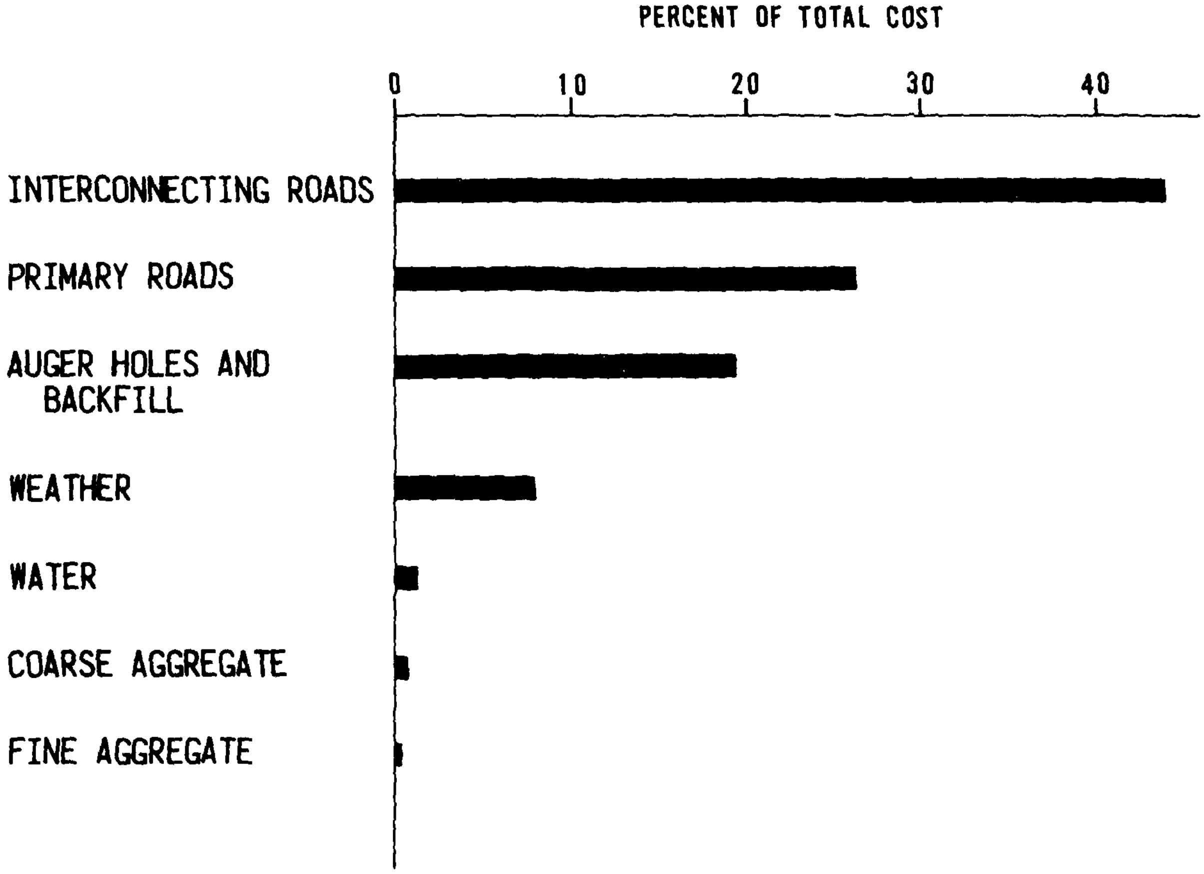
4.3.1 Parameters

The construction and material parameters evaluated for the vertical shelter basing mode are listed in Figure 4.3-1. This bar chart also shows the relative importance of each item with respect to percentage of cost. The percentage of cost for each item is based on the average cost for all CSRs and the total cost is only for the items listed. It does not include labor or material costs unaffected by geotechnical parameters such as mobilization costs, processing plants, cement, steel, etc.

The data in Figure 4.3-1 indicates that there are three items significantly affected by geotechnical parameters: interconnecting roads, primary roads, and excavations (auger holes). The materials needed for concrete, coarse and fine aggregate and water, are of lessor importance.

4.3.2 Geotechnical Ranking Results

The geotechnical ranking results are shown in Figure 4.3-2. The bar chart shows the ranking order based on a baseline nominal relative cost of 100 for the CSR with the least cost. Using this process, the difference in relative cost of a given CSR with the baseline cost of 100 is approximately equal to the percent increase in the costs. For example, the nominal relative cost of CSR A is 128, indicating that, for the items listed, nominal construction costs would be about 28 percent greater in CSR A than in CSR C. Translating this into dollars



RELATIVE IMPORTANCE OF GEOTECHNICAL FACTORS HARD VERTICAL SHELTER

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 4.3-1

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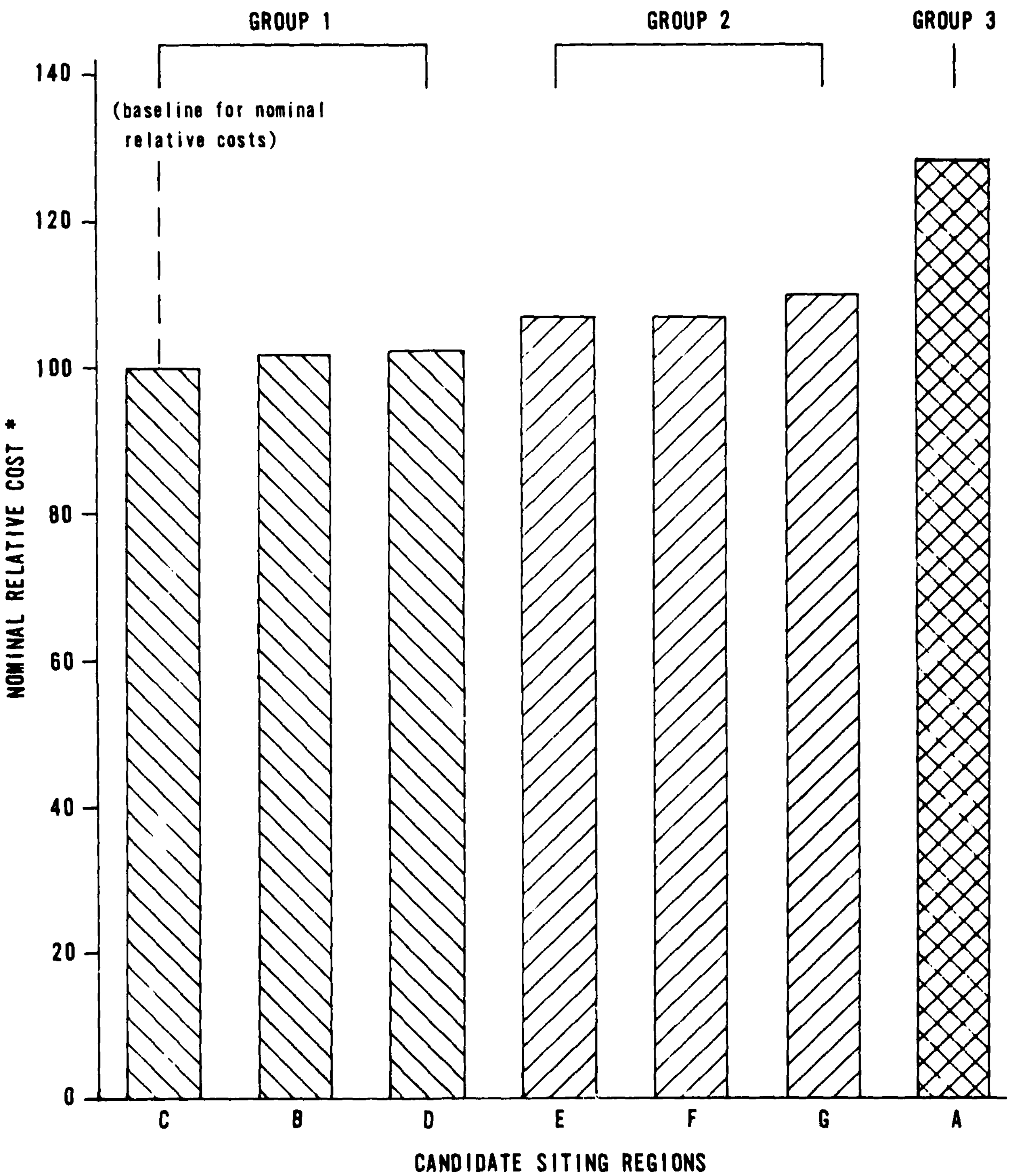

* Does not include cement, flyash, reinforcing steel, steel shaft liners, equipment building, land costs, etc.

PRELIMINARY CSR GEOTECHNICAL RANKING
HARD VERTICAL SHELTER

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE 4.3-2

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for constructing 5,000 vertical shelters, the cost difference is more than $455,000,000.

Based on the relative costs shown in Figure 4.3-2, the CSRs have been divided into Groups 1, 2, and 3 as listed below:

Group	Range in Nominal Relative Cost	CSRs
1	100 - 105	C, B, D
2	105 - 110	E, F, G
3	>110	A

The range in relative cost is only seven percent for five of the seven CSRs, indicating generally favorable conditions in all these siting areas. A more detailed probabilistic ranking must be completed before the final pre-verification ranking can be completed. It is possible that CSRs presently having a Group 2 rating could move into Group 1 when the more detailed study is completed.

4.4 IN-LINE HYBRID TRENCH

4.4.1 Parameters

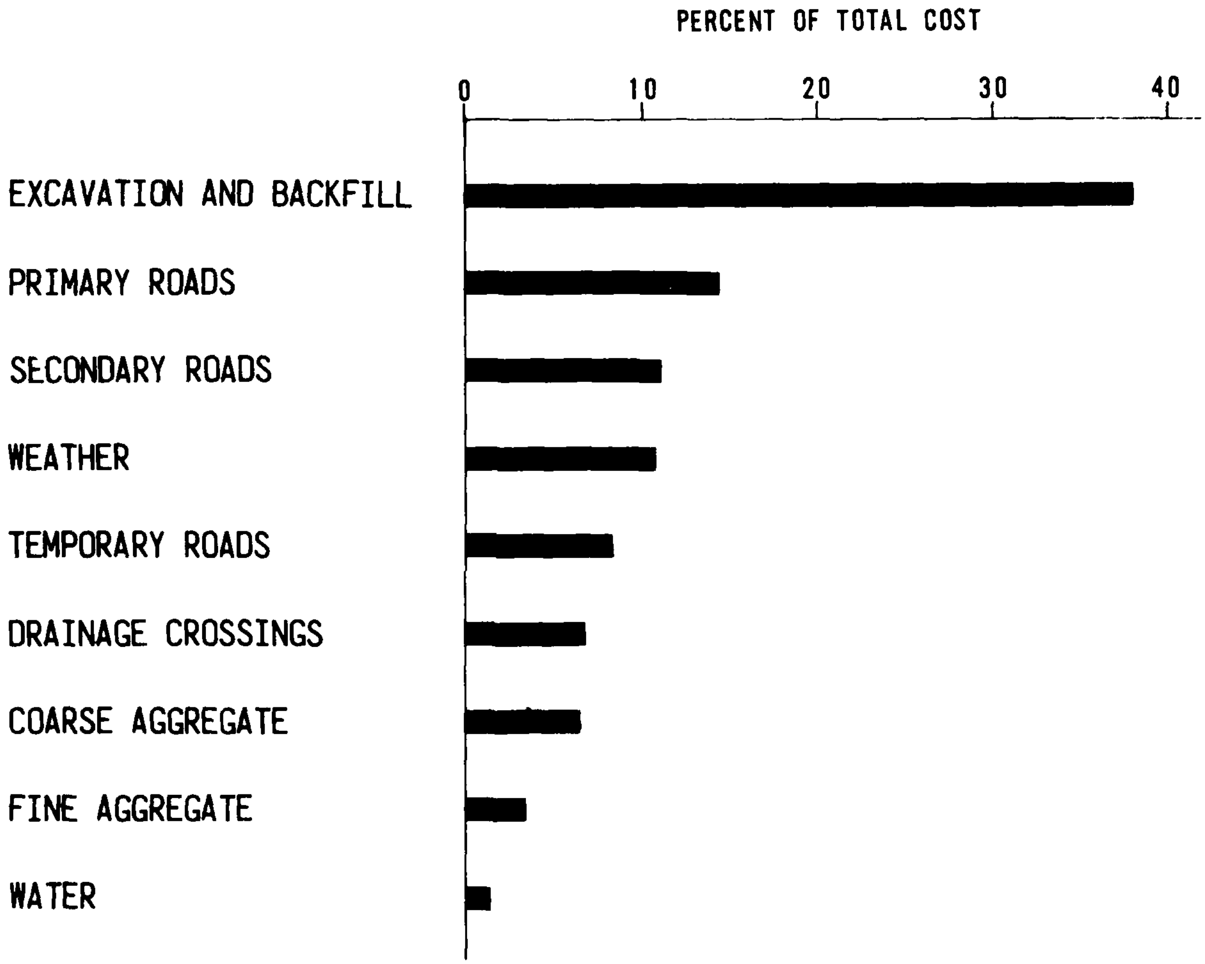
The construction and material parameters evaluated for the in-line hybrid trench basing mode are listed in Figure 4.4-1. The relative costs shown on the figure indicate that excavation and backfill is the major cost item, however, the accumulative costs of primary roads, secondary roads, and temporary roads are nearly as great. Because of the quantities of concrete needed for trench construction, the relative costs of coarse and fine aggregate are more significant than for the vertical shelter concept.

4.4.2 Geotechnical Ranking Results

The geotechnical ranking results are shown in Figure 4.4-2. Because the range in relative costs are within ten percent, the CSRs have been divided into two groups as listed below:

Group	Range in Nominal Relative Cost	CSRs
1	100 - 105	D, B, A, F
2	105 - 110	C, E, G

Not only is the total range in costs relatively small, the relative costs for the first three CSRs (D, B, and A) and last three CSRs (C, E, and G) are nearly the same. Nevertheless, the estimated difference in cost between CSRs D and F is more than $150,000,000 for 5,000 nautical miles (9,270 km^2) of trench when considering only the parameters listed. Actual differences would probably be greater when all factors are considered.



RELATIVE IMPORTANCE OF GEOTECHNICAL FACTORS IN-LINE HYBRID TRENCH

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 4.4-1

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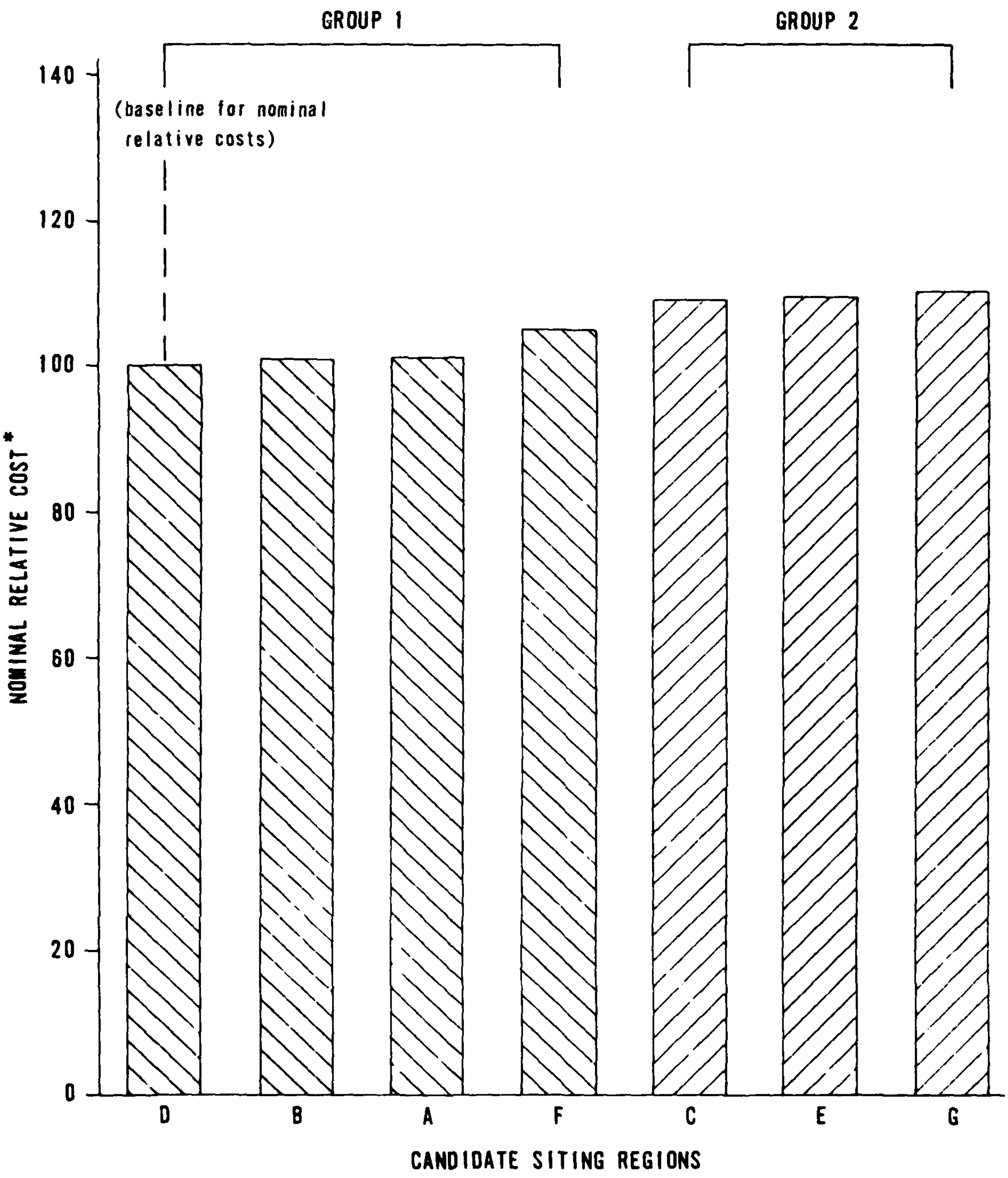

* Does not include placing cost or cost for cement, flyash, reinforcing steel, land costs, etc.

PRELIMINARY CSR GEOTECHNICAL RANKING
IN-LINE HYBRID TRENCH

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 4.4-2

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4.5 RANKING COMPARISON

The preliminary results of the ranking comparison for the hard vertical shelter and hybrid trench are shown in Figure 4.5-1. Only CSRs B and D are in Group 1 for both rankings. CSRs E and G remain in Group 2 for both rankings, and CSRs A, C, and F switch from one group to another.

Based on the level of effort which has been performed for this preliminary ranking, it is concluded that all CSRs in Groups 1 and 2 are suitable and more detailed studies are needed to determine the ranking priority. Only CSR A should be considered unsuitable for the vertical shelter basing mode.

The reason rankings change for two basing modes is because the parameters affecting costs change. For the hybrid trench, excavation and backfill are the most important parameters; they depend on the soil conditions within 20 feet (6 m) of the surface. For the vertical shelter, roads are the most important parameter; they depend on the soil conditions in the upper five feet (1.5 m). Excavations are the second most important parameter; costs are dependent on soil conditions in the upper 120 feet (37 m).

One geotechnical condition that affected the vertical shelter but did not affect the trench was the depth to ground water. The suitable areas determined from the screening study were to have a depth to water of 50 feet (15 m) or more.

GROUP	VERTICAL SHELTER, HARD	IN-LINE HYBRID TRENCH
1	C	D
	B	B
	D	A
		F
2	E	C
	F	E
	G	G
3	A	

GEOTECHNICAL RANKING COMPARISON
HARD VERTICAL SHELTER AND
IN-LINE HYBRID TRENCH

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 4.5-1

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Excavations for vertical shelters will extend about 120 feet (37 m) below the ground surface and ground water is likely to be encountered in some areas.

CSR A is the best example of the effect the basing mode has on ranking. For the trench concept, excavation and backfill is the most important construction item and CSR A had one of the lowest costs for this item. For the vertical shelter, interconnecting roads are the most important item and CSR A has the highest cost. The estimated interconnecting road construction cost in CSR A is more than 40 percent higher than the average of the other six CSRs. This high cost is due to the fact that a large percentage of the surficial soils consist of silts and clays which have low bearing strength, requiring thick design sections for supporting heavy vehicles. In addition, sources of coarse aggregates are very limited and base course materials will have to be imported. The lack of coarse aggregate also increases concrete costs.

The fact that all CSRs have nearly equal ranking with regard to geotechnical factors indicates that the fine screening criteria and application were successful. Those areas with adverse terrain, geologic, and soil conditions were eliminated during the screening process and the remaining suitable sites generally have favorable geotechnical conditions.

5.0 GEOTECHNICAL SUPPORT STUDIES

The availability of specific data to support cost and engineering analysis directly related to fielding the MX system is often lacking. The following individual studies relate more to supporting the task of obtaining design or cost data rather than the prime task of assisting in selecting the best siting region.

5.1 RESOURCES

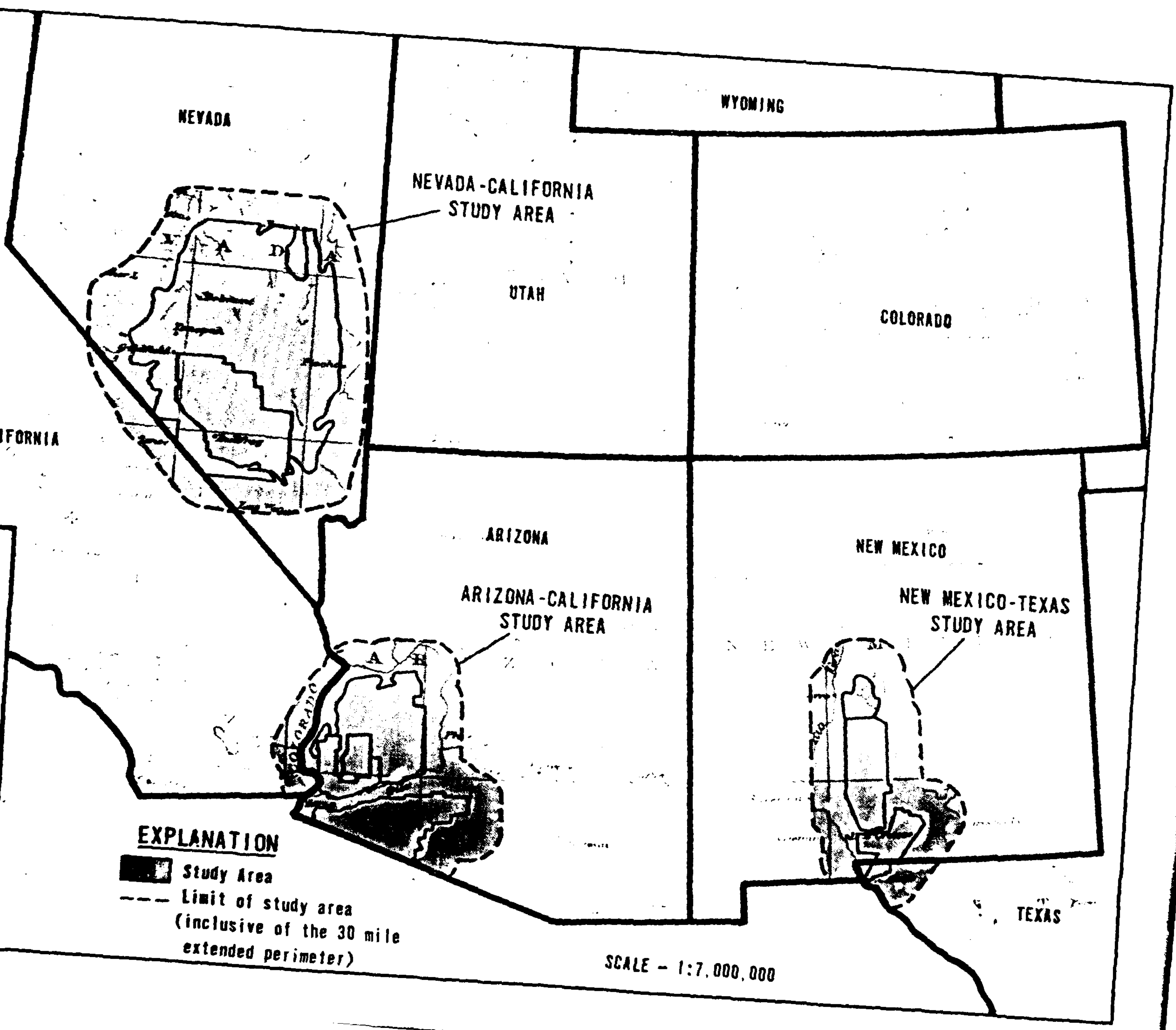
5.1.1 Aggregate Resources Evaluation Investigation (AREI)

Department of Defense and Bureau of Land Management Lands (Figure 5.1-1) were examined to determine the quantity and quality of aggregate required for MX deployment. The details of this study are contained in report FN-TR-15. The survey areas included:

1. New Mexico-Texas Survey Area (NMTSA); including the White Sands Missile Range (WSMR) and Fort Bliss Military Reservation (FBMR);

2. Arizona-California Study Area (ACSA); including the Yuma Proving Grounds (YPG), Luke Bombing and Gunnery Range (LBGR), the Gila Bend Group (GBG) of BLM land;

3. Nevada-California Study Area (NCSA); including the Nellis Bombing and Gunnery Range (NBGR), and the Nellis Group (NG) of BLM.



LOCATION MAP AREI STUDY AREAS

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 5.1-1

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5.1.1.1 Objectives

The objectives of the AREI were to inventory and rank sources of sand and gravel according to suitability for use as aggregate in structural concrete. Major factors considered were: (1) types of deposits--hard rock, basin-fill; (2) quality of materials using the American Society of Testing and Materials (ASTM), and Standards Specifications for Public Works Construction (SSPWC); (3) quantity of materials available; and, (4) accessability.

5.1.1.2 Scope of Investigation

The principal elements of the aggregate resource investigation included:

1. Collection of applicable data pertaining to the existence and quality of potential sources of concrete aggregate, and the geology, soils, and related construction materials within the study area;

2. Aerial and ground field reconnaissance and sampling of borrow pits, quarries and potential sources of aggregate.

3. Laboratory testing to determine:
   - o Resistance to abrasion of small size coarse aggregate,
   - o Soundness of aggregate,
   - o Grain size distribution of fine and coarse aggregate,

4. Development and application of a concrete aggregate sources preliminary ranking system;

5. Review of existing data on water availability and land transportation facilities;

6. Preparation of reports and graphics.

5.1.1.3 Results

The necessary quantities of aggregate to satisfy the MX system requirements were determined to be available from a variety of sources. In most cases, aggregate will need to be processed to meet standard specifications. Potential aggregate sources were divided into Classes A, B, and C as follows:

Class A

Potential sources of high quality aggregate not requiring the use of special cements or admixtures. Only nominal processing should be necessary to meet known requirements for concrete.

Class B

Potential source of possible concrete aggregate exhibiting one or more undesirable characteristics which make it of poorer quality than Class A. Further investigations will be required to determine aggregate suitability and concrete characteristics.

Class C

Material considered unsuitable for use as concrete aggregate.

Locations of these sources, their geologic unit designations, their class designation, and geologic field stations are indicated on Drawings 5.1-A through 5.1-C.

5.1.2 Water Resources, San Cristobal Valley, Arizona

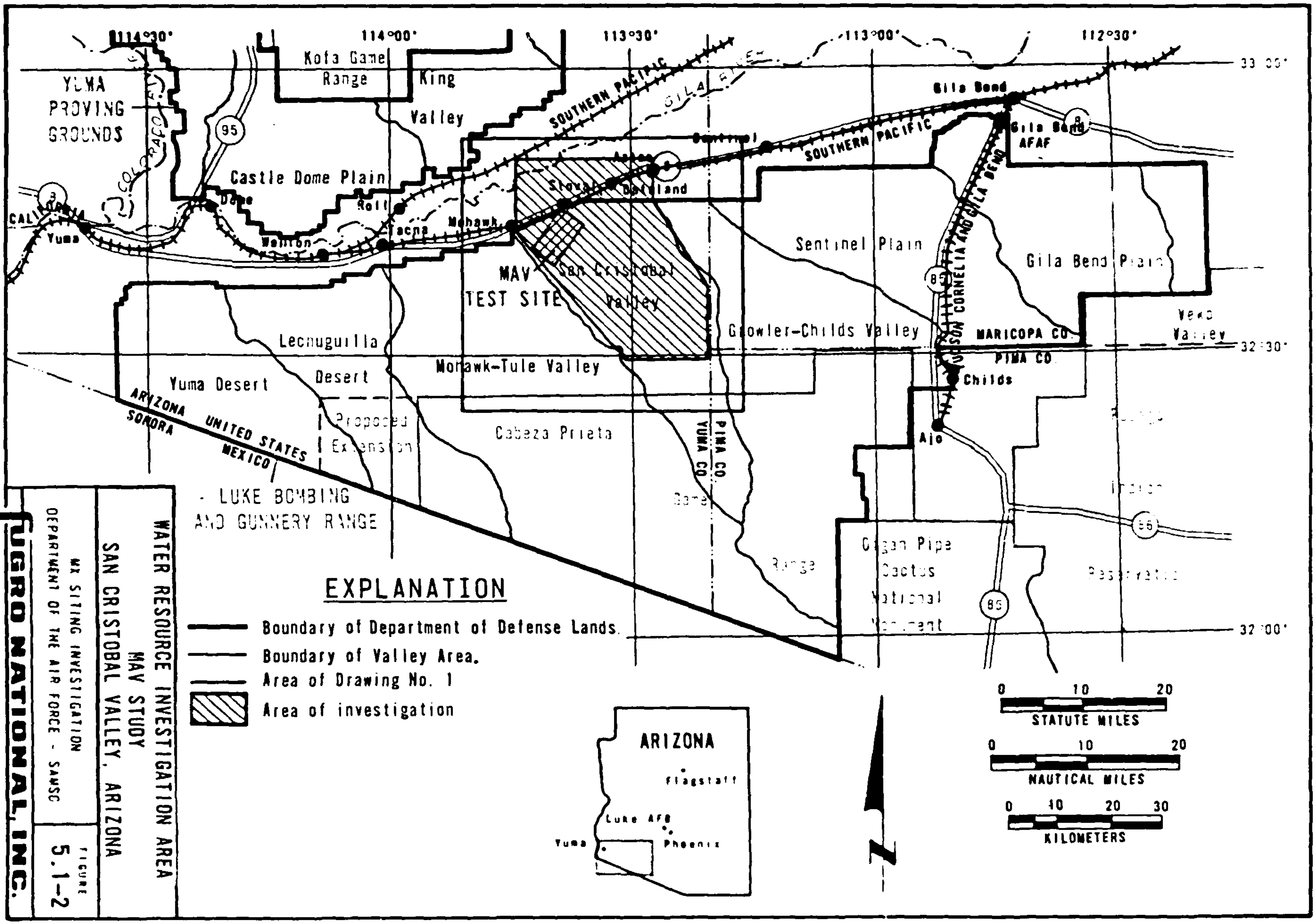
An evaluation of water resources was performed in San Cristobal Valley, Yuma County, Arizona (Figure 5.1-2). The study was to provide data for selecting a water source to supply the MAV construction project with 68.6 million gallons of water over a four-month period. Two alternatives were addressed; (1) determination of existence and character of on-site water resources; (2) evaluation of cost of delivering water from off-site water sources (Table 5.1-1). In addition, sufficient information to allow assessment of potential impact from resulting water use was addressed.

5.1.2.1 Method of Investigation

A literature review and water well survey were conducted for the Stoval Airfield area. In addition, three ground-water exploration wells were drilled, two to depths of 1000 feet (310 m) and one to 530 feet (160 m). These wells were used to determine aquifer locations and characteristics (e.g., depth to water, water flow rates), and to obtain samples for water quality testing.

5.1.2.2 Results

Six alternative sources of water were identified and evaluated. Tables 5.1-1 and 5.1-2 present cost estimates for water from each of the sources. Drawing 5.1-D shows well locations, water levels, and alternate sources and pipeline routes. Cost evaluations indicate obtaining water from the existing Dateland well and drilling two wells on the site at SC-D-1 are the most viable alternatives. Use of the proven Dateline well was recommended



YUMA PROVING GROUNDS
Kofa Game Range
King Valley
Castle Dome Plain
COLORADO R.
GILA RIVER
SOUTHERN PACIFIC
Gila Bend
Gila Bend AFAF
Yuma
Dome
Wellton
Roll
Tacna
Mohawk
Stoval
Aztec
Dateland
Sentinel
Sentinel Plain
Gila Bend Plain
Vekol Valley
MAV TEST SITE
San Cristobal Valley
Growler-Childs Valley
MARICOPA CO.
PIMA CO.
YUMA CO.
Childs
Ajo
TUCSON CORNELIA AND GILA BEND
Lecnuguilla Desert
Yuma Desert
Mohawk-Tule Valley
Cabeza Prieta
Proposed Extension
ARIZONA SONORA
UNITED STATES MEXICO
LUKE BOMBING AND GUNNERY RANGE
Organ Pipe Cactus National Monument
114°30'
114°00'
113°30'
113°00'
112°30'
33°00'
32°30'
32°00'
EXPLANATION
Boundary of Department of Defense Lands.
Boundary of Valley Area.
Area of Drawing No. 1
Area of investigation
ARIZONA
Flagstaff
Luke AFB
Phoenix
Yuma
0 10 20 STATUTE MILES
0 10 20 NAUTICAL MILES
0 10 20 30 KILOMETERS
WATER RESOURCE INVESTIGATION AREA
MAV STUDY
SAN CRISTOBAL VALLEY, ARIZONA
MX SITING INVESTIGATION
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FIGURE 5.1-2
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Source	Estimated Well Construction Cost	Estimated Pumping Cost[1]	Approximate Water Purchase Cost	Estimated Well Testing Cost[2]	Estimated Cost Exclusive of Transportation and Treatment
Wellton-Mohawk Drain	-0-	$ 5,000.00	-0-	-0-	$ 5,000.00
Wellton-Mohawk Canal	-0-	5,000.00	$ 3,150.00	-0-	8,150.00
Well C-07-12-19 cca at Dateland	-0-	-0-	10,500.00	-0-	10,500.00
Well C-07-13-31 ccb north of Stoval Field	-0-	10,000.00	2,100.00	$45,000.00	57,100.00
Three Well Field at Stoval Field	$ 80,000.00	30,000.00	-0-	50,000.00	160,000.00
Two Well Field at SC-D-1	$100,000.00	24,000.00	-0-	45,000.00	169,000.00

NOTES:

(1) Estimated on four months of operation

(2) Based on 10 day test

ESTIMATED COST FOR WATER ALTERNATE SOURCES

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE 5.1-1

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Source (Distance from Stoval Field - miles)	Estimated Cost Exclusive of Transportation and Treatment	Estimated Transportation Cost		Estimated Treatment Cost	Estimated Total Cost at Site Using	
		Aluminum Pipe	Steel Pipe		Aluminum Pipe	Steel Pipe
Wellton-Mohawk Drain (10.75)	$ 5,000.00	$ 68,800.00	$173,300.00	$500,000.00	$573,800.00	$678,300.00
Wellton-Mohawk Canal (9.4)	8,150.00	60,200.00	155,300.00	Negligible	68,350.00	163,450.00
Well C-07-12-19 cca at Dateland (7.4)	10,500.00	47,400.00	122,500.00	Negligible	57,900.00	133,000.00
Well C-07-13-31 ccb north of Stoval Field (3)	57,100.00	19,200.00	50,400.00	$500,000.00	576,300.00	607,500.00
Three Well Field at Stoval Field	160,000.00	Negligible		500,000.00	$660,000.00	
Two Well Field at SC-D-1 (4.2)	169,000.00	26,900.00	70,100.00	Negligible	195,900.00	239,100.00

ESTIMATED COST FOR WATER DELIVERED TO STOVAL FIELD

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE 5.1-2

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because of the favorable aquifer characteristics, and the minimum impact on the area. The study also indicated that producing any of the identified ground water sources would have little or no adverse effect on vegetation or surrounding wells.

5.1.3 Water Resources, DoD Lands

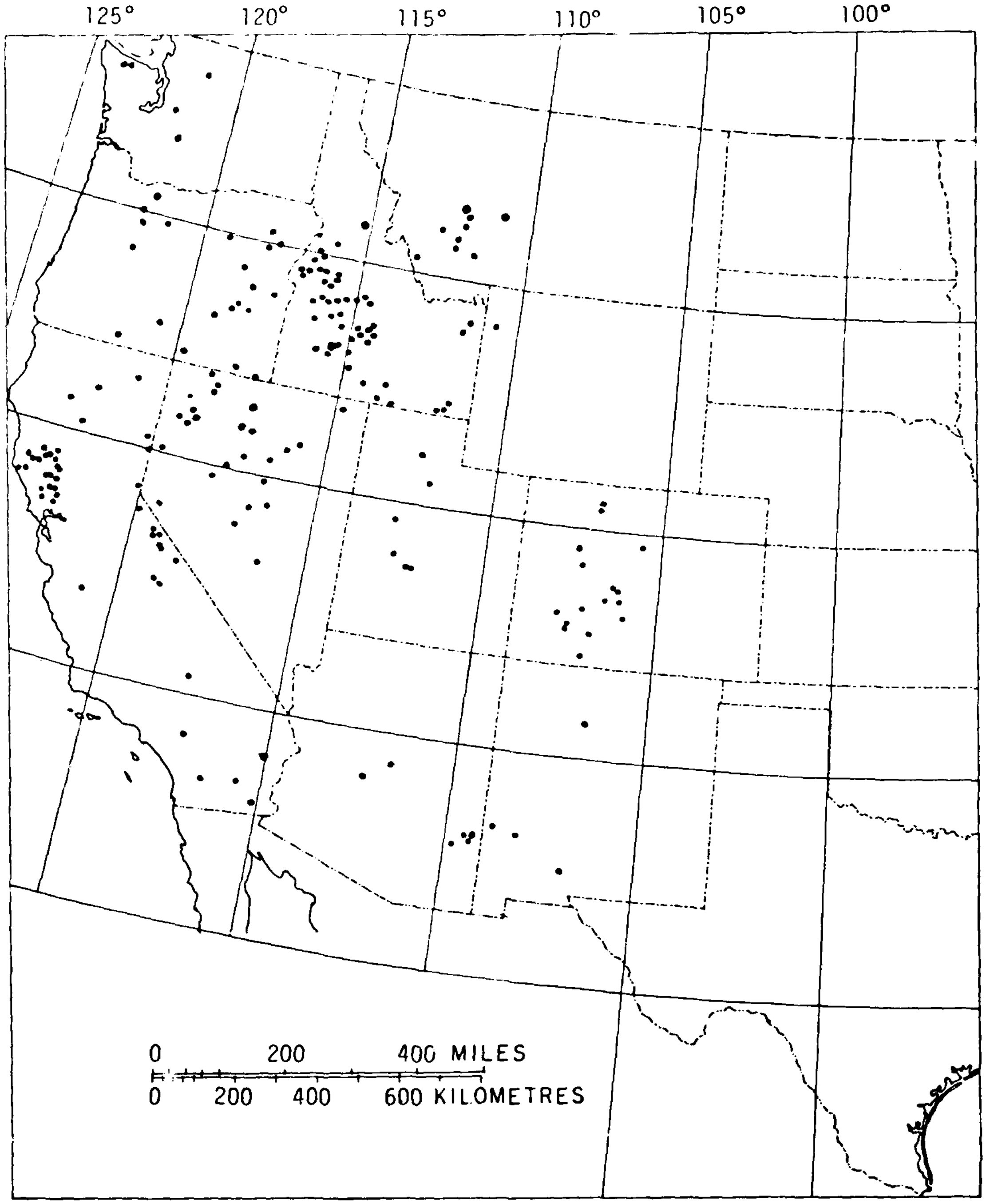
A water rights and resources ivestigation was conducted in three DoD potential siting areas; WSMR/FBMR, YPG/LBGR and NBGR. The objective was to evaluate water requirements, availability and legal rights relative to a pool basing mode. The study results indicate there is sufficient water for pools, however, detailed studies are required to verify availability (e.g., legal) and environmental impact of withdrawal.

5.1.4 Energy

The literature review conducted for the Screening studies (Section 2.0) provided an extensive data bank that includes locations of existing and potential energy sources. In addition to conventional power sources, known geothermal resource areas (KGRAs) are well located and could be developed to provide energy for the MX system. These areas are depicted in Figure 5.1-3. Although these data are available, they have not yet been reported.

5.1.5 Other Raw Materials

Data pertaining to potential sources of construction materials are part of the acquired data bank. However, they have not been formally investigated.



• - Location of hydrothermal convection systems in the conterminous United States with indicated subsurface temperatures between 90° and 150°C.

Reference: U.S. Geological Survey Circular 726

KNOWN GEOTHERMAL RESOURCE AREAS

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 5.1-3

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5.2 DIGITAL TERRAIN DATA

5.2.1 Introduction

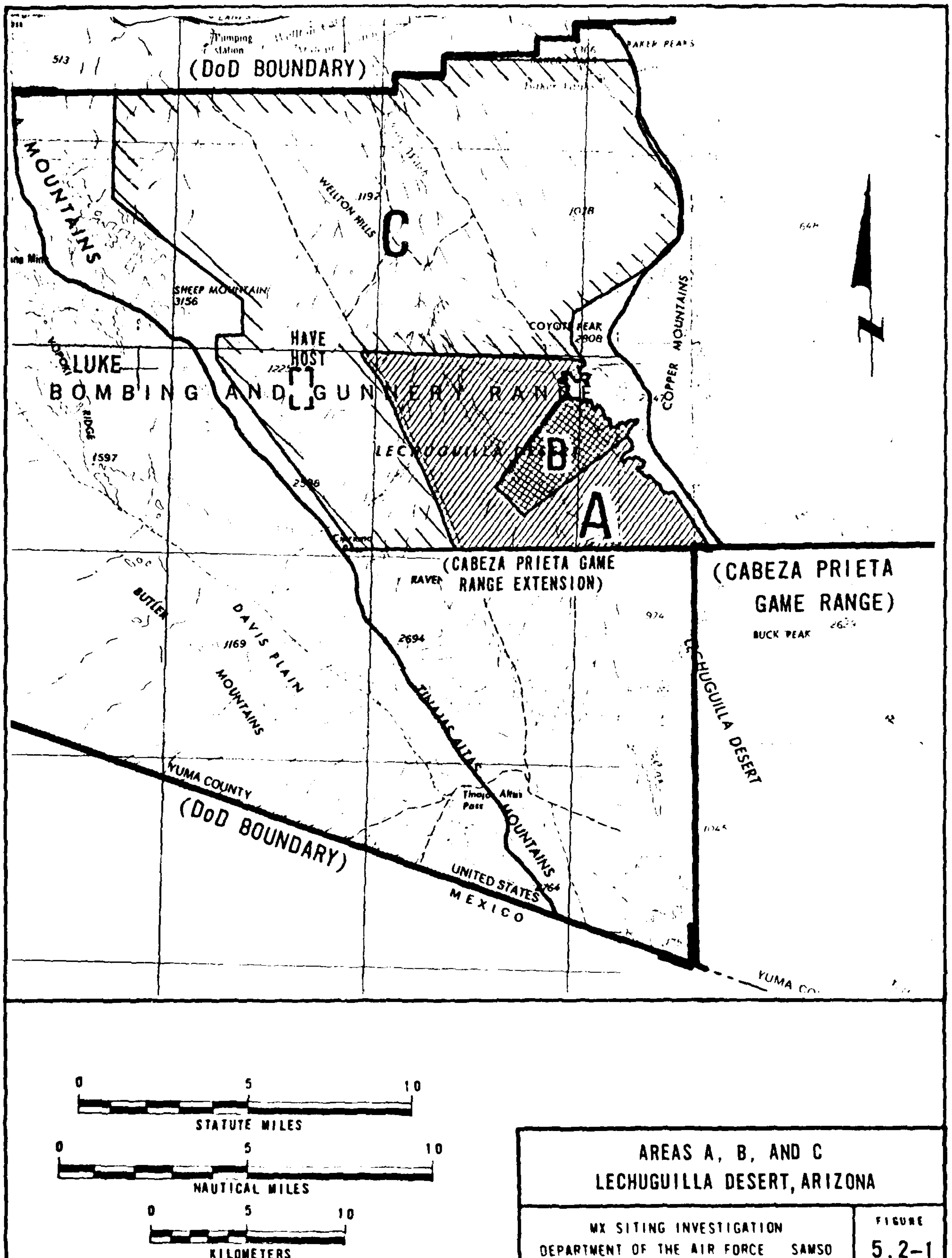
Report FN-TR-22 presented the results of a study that included obtaining aerial photos, processing of digital terrain data (DTD), and development of site configuration computer programs.

To produce realistic site layouts, it is necessary to consider terrain conditions and determine the best orientation of system components that meet grade and spacing requirements. This was the objective of this study.

The DTD study developed basic computer programs which rapidly and efficiently produce site layouts. State-of-the-art techniques of obtaining and processing photogrammetrically derived topographic survey data were used. A portion of Lechuguilla Desert, a potential siting area within LBGR, was selected as the model area (Figure 5.2-1). Most comparison studies were limited to a portion of the valley defined as Area A in Figure 5.2-1.

The terrain data obtained during the evaluation of photogrammetric survey techniques were used as input to the computer programs. The computer programs aided in the evaluation process, using actual terrain data from a potential siting region. The method selected for defining terrain features was a uniform grid spacing plus separate digitization of selected drainages.

Because there are distinct differences in methods and in costs for developing DTD, it was decided to evaluate three techniques



AREAS A, B, AND C
LECHUGUILLA DESERT, ARIZONA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE 5.2-1

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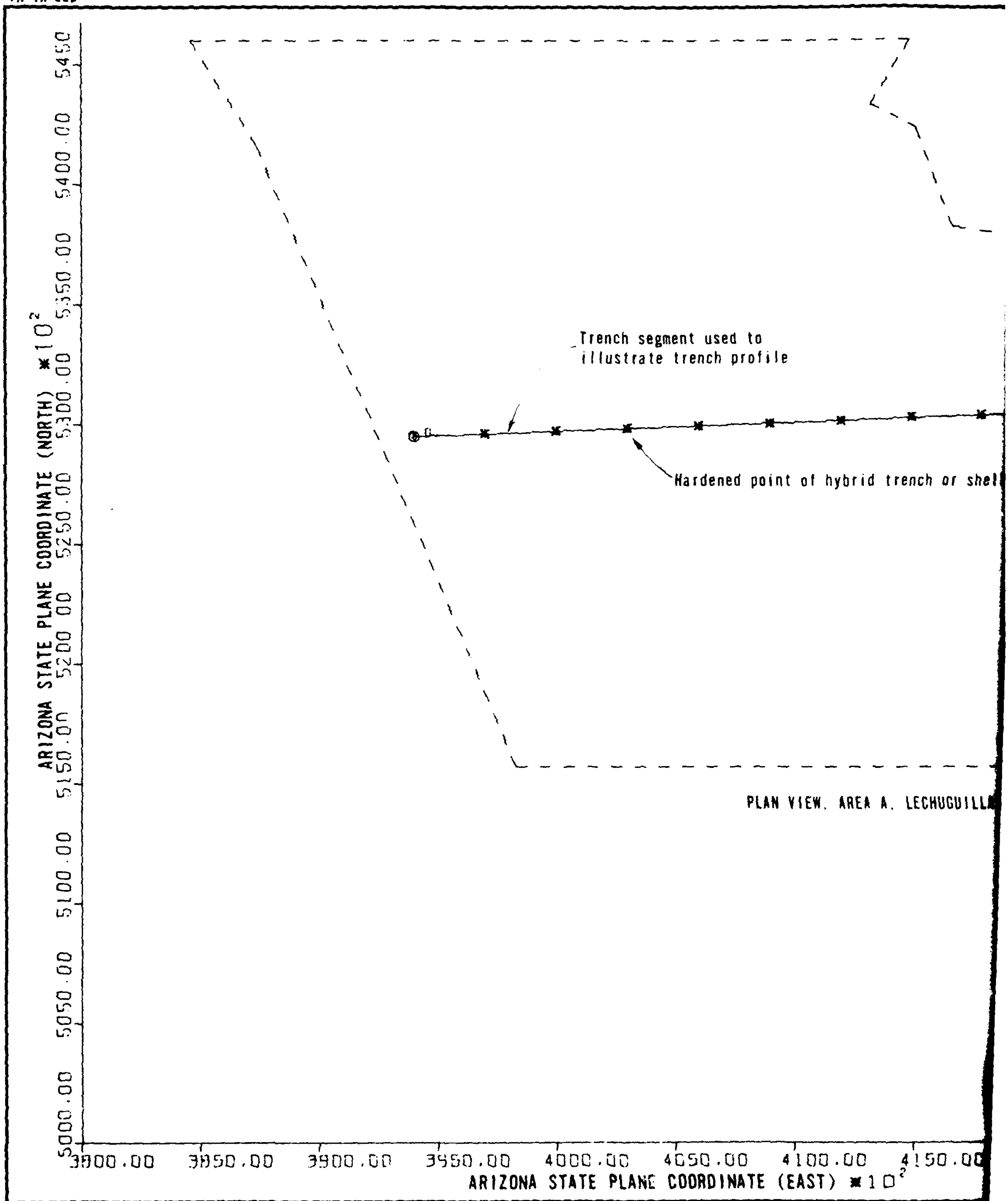
offering the greatest potential. Since the grid spacing and photographic scales varied, it was possible to evaluate the effect of these parameters on the final results.

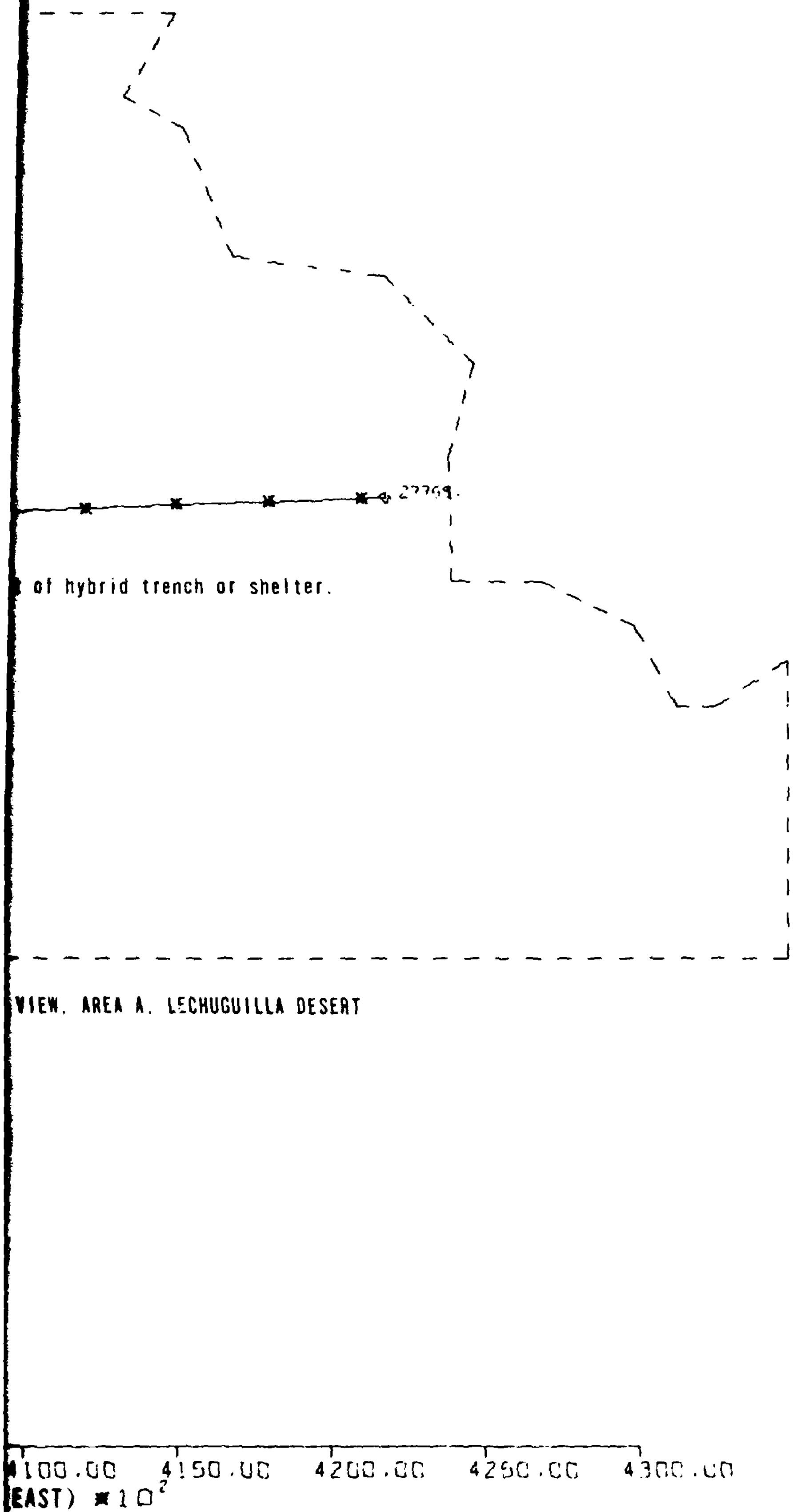
5.2.2 Summary of Results and Recommendations

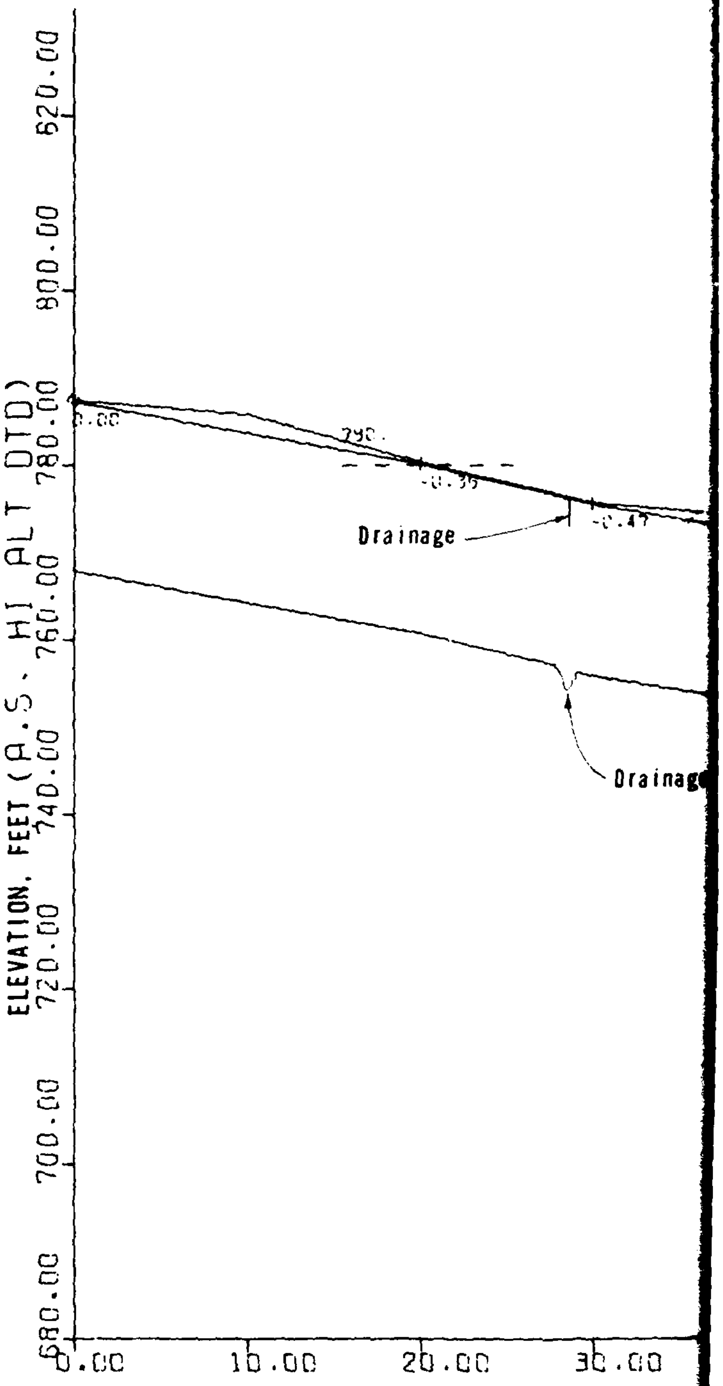
Five computer programs were developed during the study. These programs were originally designed for the continuous trench basing mode, but can be modified for the shelter concepts. Figure 5.2-2 is a computer derived plan view and profile of a trench system. The printout on the plan view could be modified to show hardened points of a hybrid trench or shelters.

Adequate site layouts for preliminary design can be obtained using black and white aerial photographs at a scale of 1:24,000 and a uniform grid spacing of 400 feet (120 m). Gridded DTD can be satisfactorily produced using conventional stereo plotter methods, digitization of contours methods, or the Gestalt Photo Mapper.



Trench segment used to illustrate trench profile
Hardened point of hybrid trench or shel
PLAN VIEW. AREA A. LECHUGUILL
ARIZONA STATE PLANE COORDINATE (NORTH) $*10^2$
5450
5400.00
5350.00
5300.00
5250.00
5200.00
5150.00
5100.00
5050.00
5000.00
3800.00
3850.00
3900.00
3950.00
4000.00
4050.00
4100.00
4150.00
ARIZONA STATE PLANE COORDINATE (EAST) $*10^2$


27769.
of hybrid trench or shelter.
VIEW, AREA A, LECHUGUILLA DESERT
4100.00
4150.00
4200.00
4250.00
4300.00
EAST) *10²


ELEVATION, FEET (A.S. HI ALT DTD)
820.00
800.00
780.00
760.00
740.00
720.00
700.00
680.00
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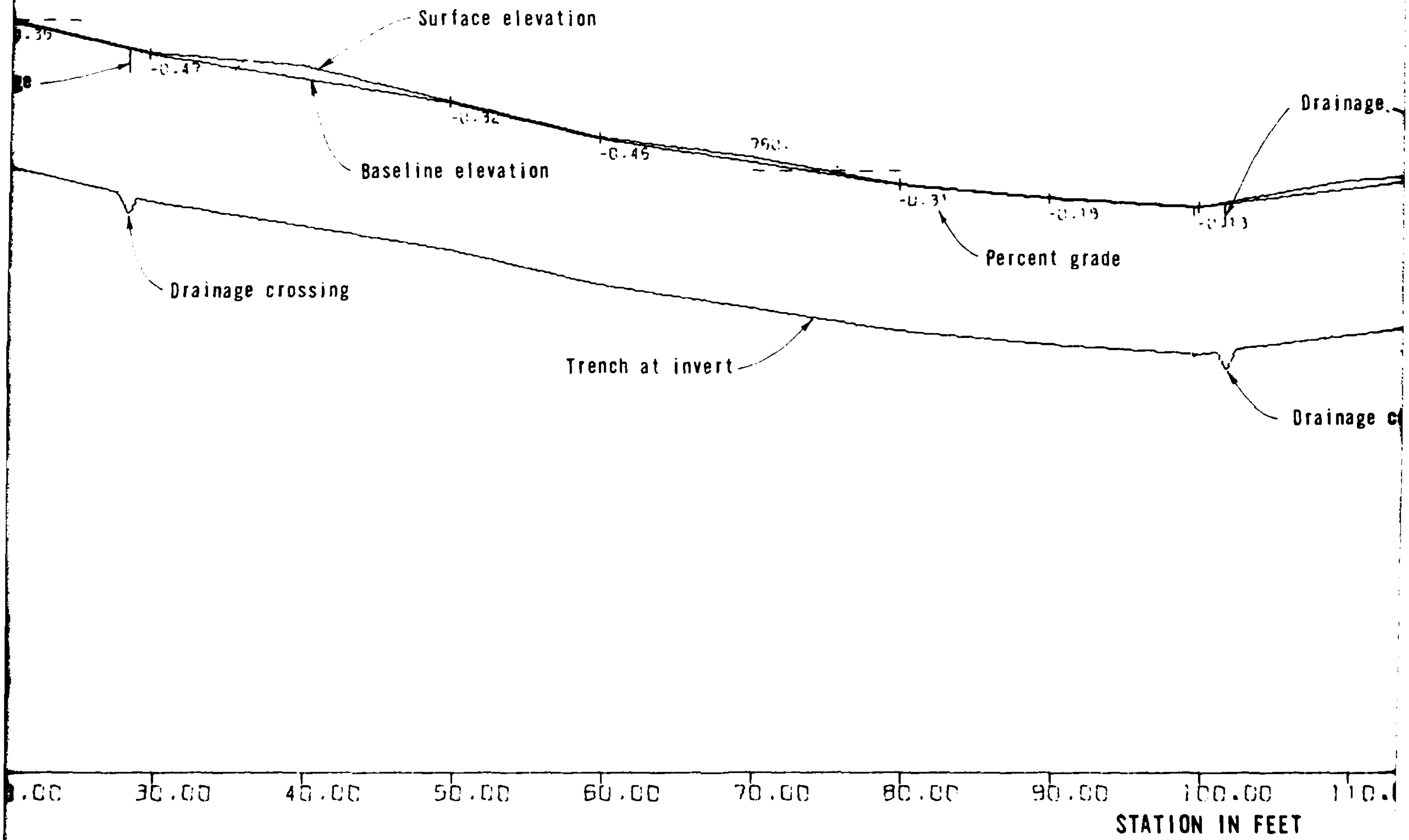
10.00
20.00
30.00
790.
-0.35
-0.47
Drainage
Drainage


Surface elevation
Baseline elevation
Drainage crossing
Trench at invert
Percent grade
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-0.47
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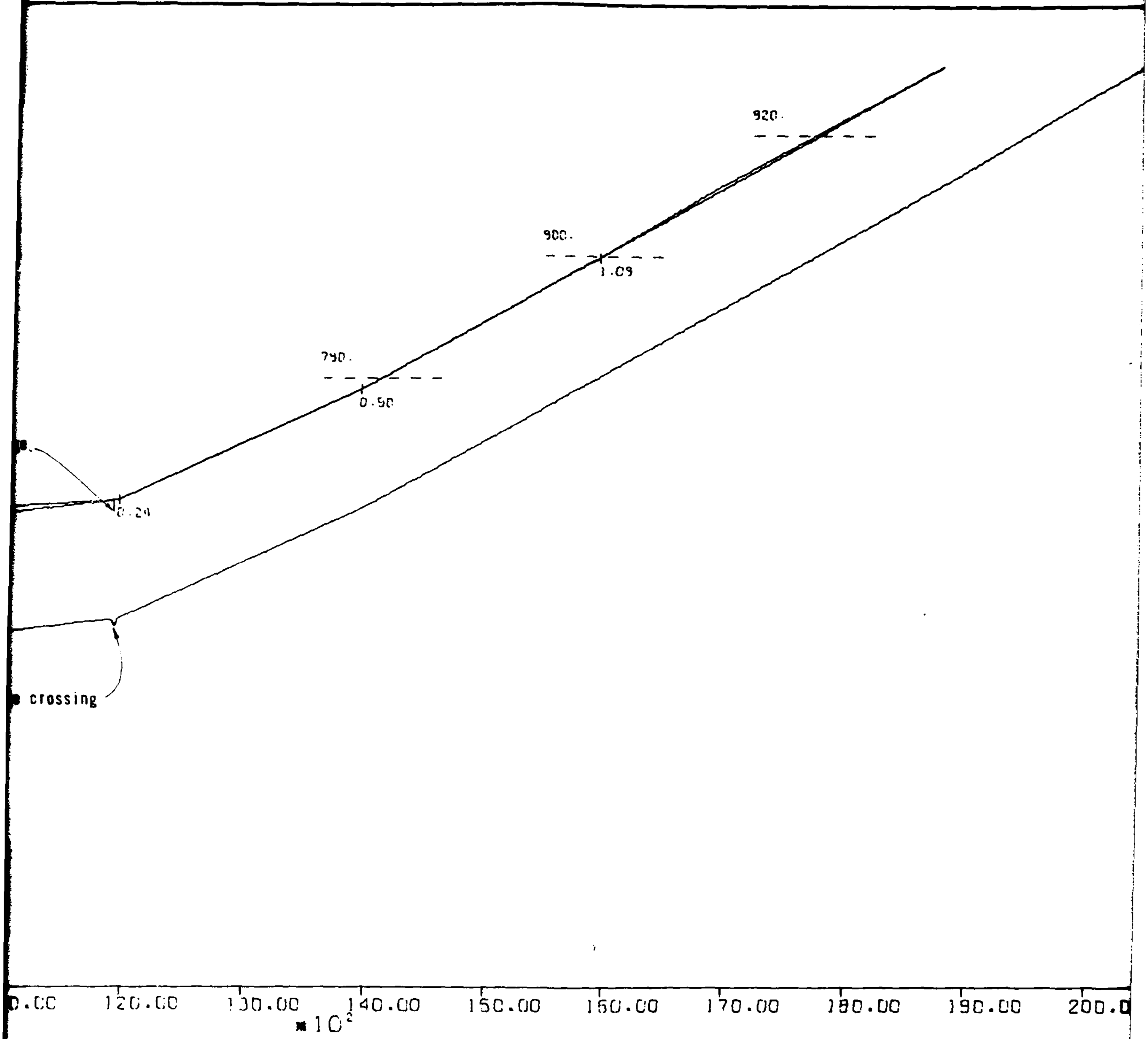
STATION IN FEET



TRENCH PLAN AND PROFILE

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 5.2

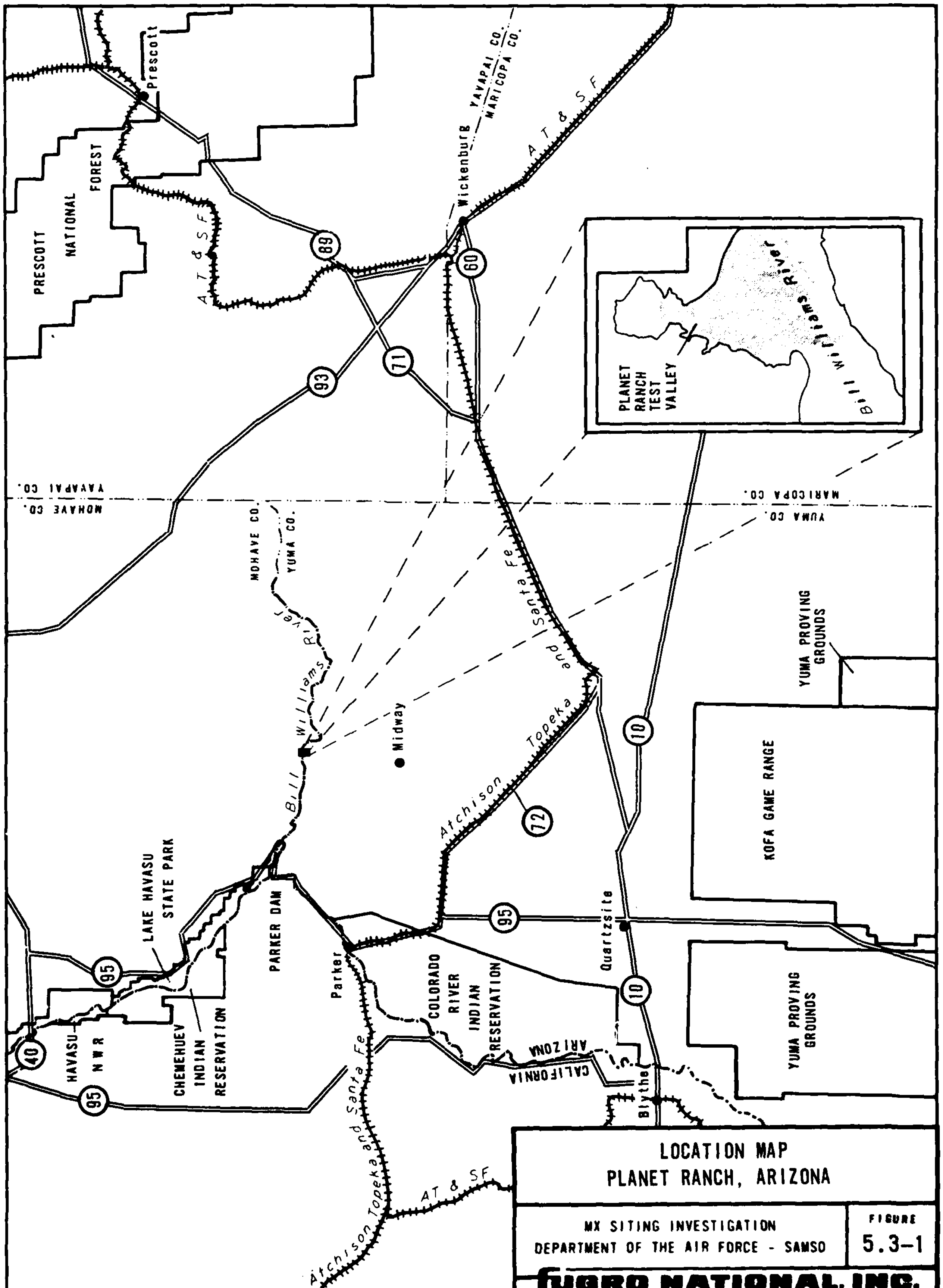
FUGRO NATIONAL, INC

5.3 MISERS BLUFF TEST PROGRAM, PLANET RANCH, ARIZONA

A geotechnical investigation was performed at Planet Ranch to support Phase II of the Defense Nuclear Agency (DNA) Misers Bluff Test (Figure 5.3-1). Phase II consists of a series of single and multi-burst high explosive events. This geotechnical investigation provided in-situ soil and rock properties data required for planning and analysis of the proposed tests. This site was selected because its geology (dry soil strata over wet soil strata over bedrock) models the desired MX siting conditions, and the depths to water and bedrock were of the desired scaled depths for a 109,000 kg (120 ton) explosive charge. Furthermore, the Planet Ranch site lies within a small valley from which it may be possible to observe seismic "reverberation" effects. The 109,000 kg (120 ton) charge size was selected to ensure that the wet soil and bedrock strata were exercised and, in the multiple-burst event, that reverberation effects, if any, could be observed.

5.3.1 Objectives

The objectives of Phase II tests are to obtain ground motion data from a representative MAP geology and to evaluate and refine the multi-burst waveform synthesis model developed from Phase I data. A number of Department of Defense and foreign agencies will also field experiment utilizing the ground motion and air shock environments generated by the Phase II events.



LOCATION MAP
PLANET RANCH, ARIZONA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 5.3-1

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5.3.2 Scope

The geological study included field investigations, laboratory testing, and compilation and analysis of the acquired data.

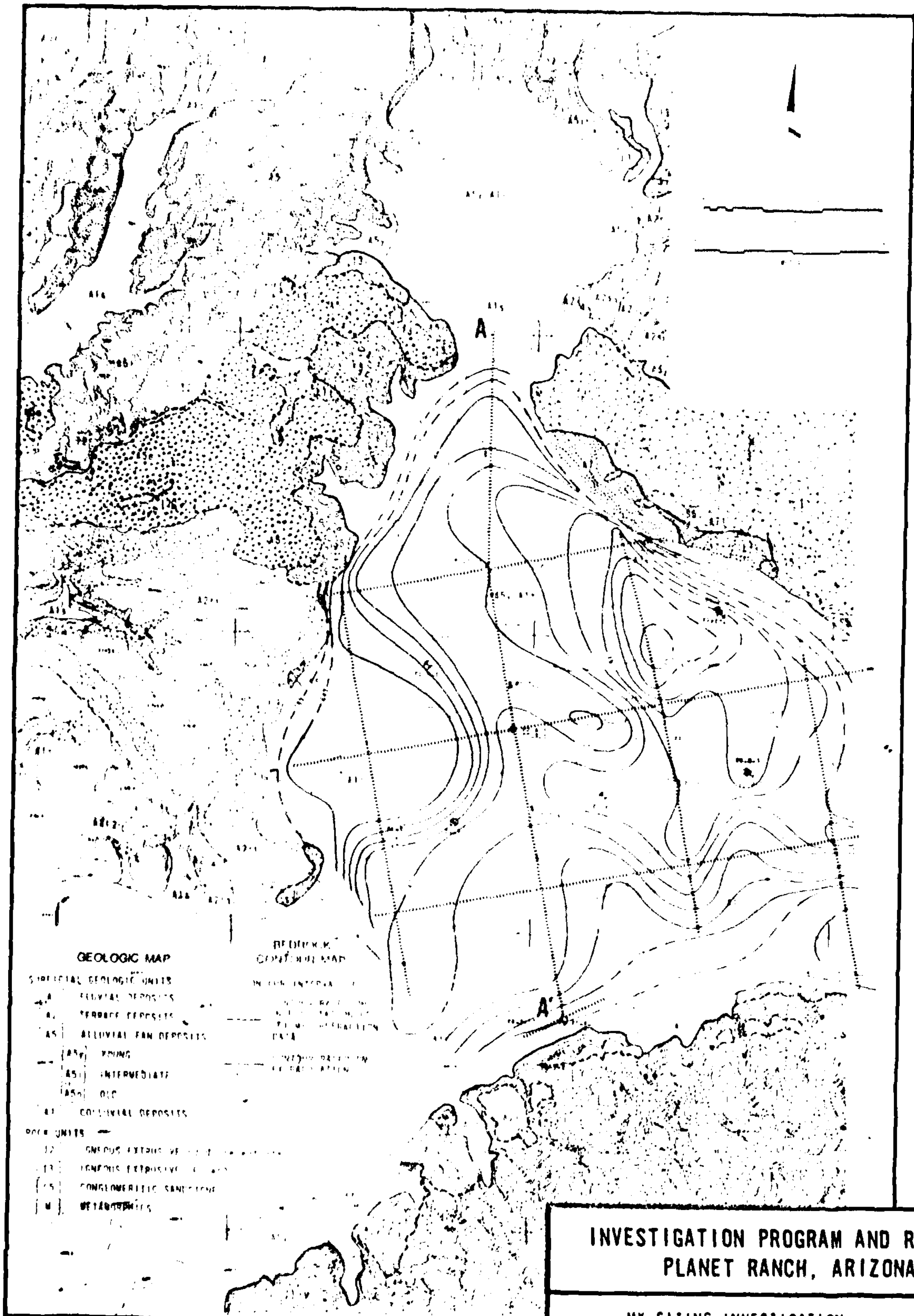
The field phase of the investigation included gathering geologic, geophysical, and engineering data designed to provide required information for Phase II test analysis. Surficial geological conditions were determined from aerial photographs and geological mapping (Figure 5.3-2). Geophysical measurements included 22,650 feet (6910 m) of seismic refraction profiles and cross-hole and downhole seismic velocity surveys. Subsurface soil information was obtained from 11 borings and six trenches (Figure 5.3-2). An example soil profile is shown in Figure 5.3-3.

A network of open well piezometers, designed to monitor fluctuations in the ground-water table, were installed in seven soil borings.

The laboratory testing program included: index tests on representative soil samples; triaxial shear tests; and relative density and compaction tests.

5.3.3 Results

Maps of the physiographic geologic and hydrologic conditions encountered at the site were provided; a description of the buried rock configuration as determined from soil borings, trench excavations and geophysical surveys were derived; and, determinations were made of the various static and in-situ elastic soil properties.



INVESTIGATION PROGRAM AND RESULTS
PLANET RANCH, ARIZONA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
5.3-2

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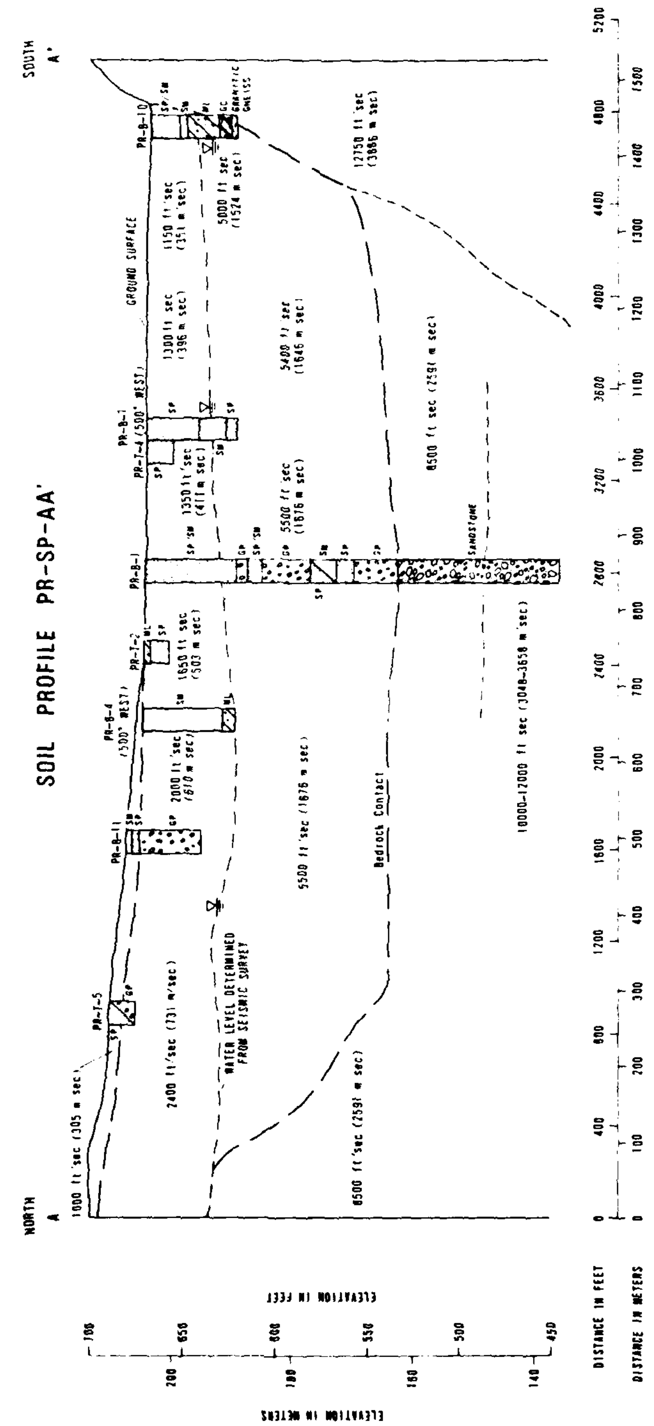


SOIL PROFILE PR-SP-AA'
PLANET RANCH, ARIZONA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE
5.3-3

FUGRO NATIONAL, INC.

The Defense Nuclear Agency has determined that the site is suitable for their purposes, and the multi-burst testing program is scheduled for implementation.

5.4 METHODOLOGY STUDIES

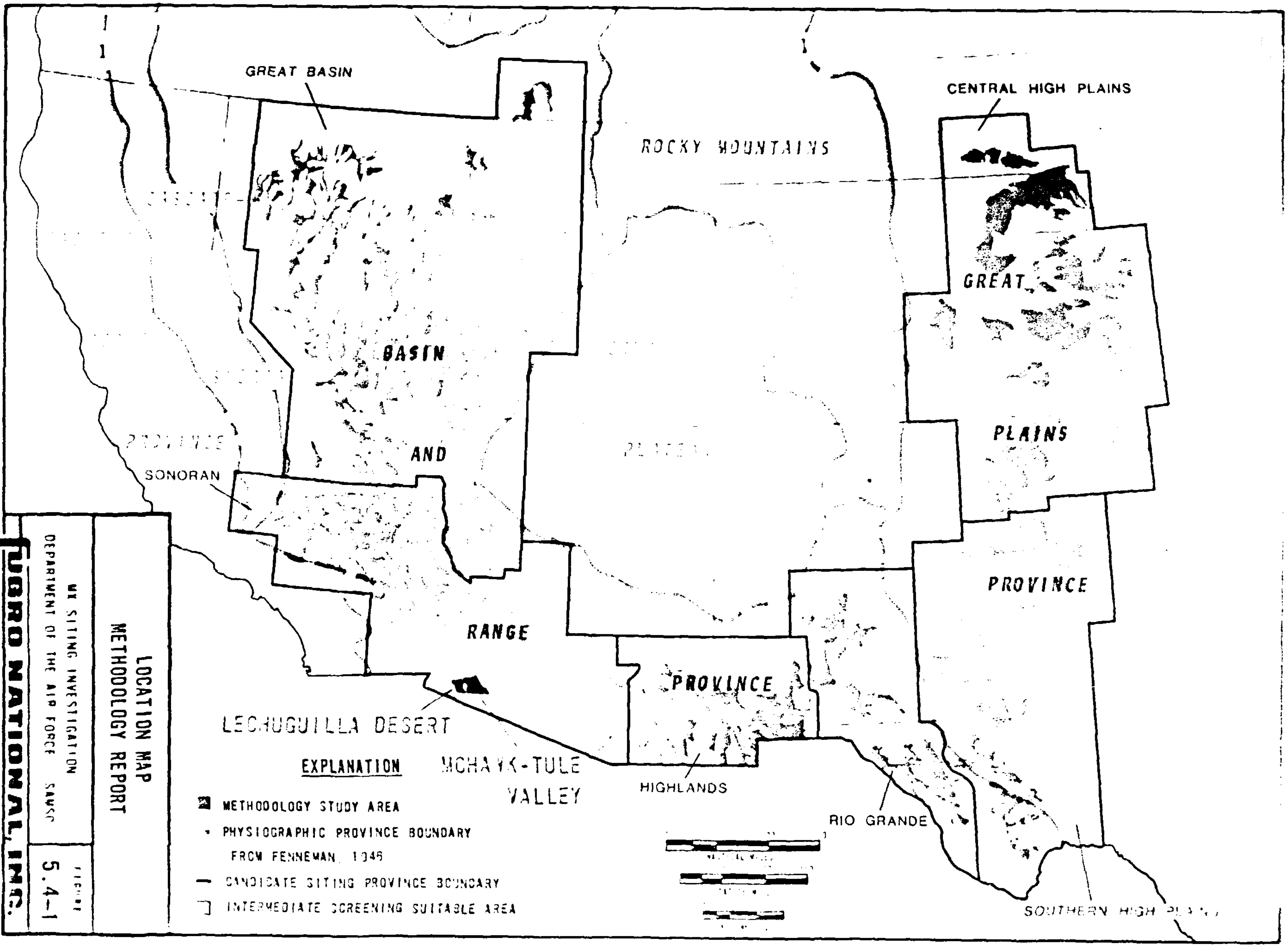
5.4.1 Background and Objectives

The Methodology study was implemented to examine the effectiveness of very large area geotechnical investigative techniques and to determine the most cost effective methods for site Verification studies. Once specific CSRs are identified, detailed site-specific investigations can be implemented to provide final design data prior to construction. These investigations will use methods identified as most cost-effective by this study. Luke Bombing and Gunnery Range was used as the principal Methodology model area. LBGR lies within the Basin and Range physiographic province (Figure 5.4-1). Applicable data from Characterization studies in the Great Plains physiographic province were used for comparison.

The investigative techniques conducted were selected on the basis of the MX siting requirements. A summary of these requirements and corresponding geotechnical investigative methods is given in Table 5.4-1.

5.4.2 Results and Uses

The geotechnical survey methods recommended for the Verification studies are listed in Table 5.4-2. Ranges of productivity and unit costs for Verification field work, as established from the Methodology study, are included in Table 5.4-2. The range of costs for data compilation, reduction, analysis and report preparation are shown as a percentage of the total cost of original data collection activities for each major discipline.



LOCATION MAP
METHODOLOGY REPORT

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE
5.4-1

FUGRO NATIONAL, INC.

GEOTECHNICAL METHODS

OTHER STUDIES · ENGINEERING · GEOLOGY · GEOPHYSICS

Methods / REQUIREMENTS	Delineate Major Surficial Geologic Units	Evaluate Terrain Features (Microrelief)	Depth to Rock	Depth to Water	Construction or Maintenance Problems	Properties of Basin-Fill Materials	Bedrock Composition	Topography	Excavation and Ripping Characteristics	Aggregate Resources	Ownership and Control	Present and Planned Future Use	Cost Data
Methodology													■
Existing Data	◐		●	●	◐	●	◑	◧		◧	◧	◧	●
Lab Testing					◐	■			◐	◐			
Trenching	◧		◐		◧	◧			◧	◐			
Soil Sampling	◧		◐		◧	■	◨		◧	◐			
Deep Borings	◐		◨	◨	◐	◨	◨		◐	◐			
Shallow Borings	◧		●	●	◧	◧	◑		◐	◐			
Subsurface Characterization	◐		■	■	◐	●	■		◧	◧			
Field Mapping	◧	◧			◧	◧	■	◧	◐	◧			
Aerial Reconnaissance	◐	◐			◐			◐	◐	◐			
Photogeology	◧	◐			◐			◧	◐	◐	◐	◐	
Downhole Geophysical Logging	◐		●	●		●	●			◐			
Downhole Velocity			■	●	◧	■			◐	◐			
Aeromagnetics	◐		●		◐		●		◐				
Gravity			◑			◑	◑						
Resistivity			◐	◐		◧			◐	◐			
Deep Seismic			◨	◑		◨	◑						
Shallow Seismic	◐		■	●	◧	◧	●		◐	◐			

APPLICABILITY

	PRIMARY	SECONDARY
CONSTRUCTION	◧	◐
V AND H	◨	◑
BOTH	■	●

MX SITING REQUIREMENTS AND SUMMARY OF GEOTECHNICAL METHODS

MX SITING INVESTIGATION
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TABLE 5.4-1

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	ACTIVITY	PRODUCTIVITY (1) UNITS PER DAY	UNIT COST (2) ($)	REPORT (3) PREPARATION
GEOPHYSICS	AEROMAGNETICS	200-350 line.mi.	13.50/line.mi.	Add 35 to 50 percent to total Geophysics field costs.
	GROUND GRAVITY	9-25 Stations	(4) (5) 80-150/Sta.	
	DEEP SEISMIC	10,000-20,000 Ft.	.80-1.10/Ft.	
	SHALLOW SEISMIC	800-1600 Ft.	.50-.90/Ft.	
	DOWNHOLE VELOCITY	100-500 Ft.(6)	2.30-10.50/Ft.	
	ELECTRICAL RESISTIVITY	2-4 Soundings	200-250/Sounding	
GEOLOGY	RECONNAISSANCE(11)	40-100 nm^2	32-37/nm^2	Add 30 to 55 percent to total Geology field costs.
	FIELD MAPPING	1-10 nm^2	30-320/nm^2	
	ENGINEERING (7) TRENCHING CHARACTERIZATION	5-3 trenches	150-800/trench	
	GEOLOGIC EXPLORATION TRENCHING	1-3 trenches	400-1200/trench	
	BORING CHARACTERIZATION	5-7 borings	50-60/boring (8)	
	PHOTOGEOLOGY	4-6 nm^2	158-170/nm^2	
ENGINEERING	SHALLOW BORINGS	40-115 Ft.	22-36 Ft.	Add 15 to 30 percent to total Engineering field costs.
	DEEP BORINGS	60-125 Ft.	23-34/Ft.	
	SOIL SAMPLING	N.A.	Included in drilling cost.	
	LABORATORY TESTING — SHALLOW BORINGS		4.50-9.00/Ft.	
	LABORATORY TESTING — DEEP BORINGS		2.00-5.00/Ft.	
	TRENCHING (9) — UNSHORED	1-3 trenches	350-1000/trench	
	TRENCHING (9) — SHORED	1-1.5 trenches	1300-2300/trench	
	CONE PENETROMETER	50-150 Ft.	7-20/Ft.	
	IN SITU TESTS	(10)	(10)	

NOTES:
(1) Units appropriate to each activity
(2) Data acquisition unit costs
(3) Includes data reduction, analysis, compilation, draft and final report.
(4) Fugro National unit cost.
(5) Projected Defense Mapping Agency cost.
(6) Performed concurrently with shallow refraction (Production rate affected by refraction production rate).
(7) Subcontractor cost for trenching included in Engineering.
(8) No data for Great Plains.
(9) Characterization costs included in Geology.
(10) Productivity and unit cost dependent on test performed.
(11) Includes Existing Literature Review

PROJECTED PRODUCTIVITY AND UNIT COSTS FOR VERIFICATION

MX SITING INVESTIGATION
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TABLE 5.4-2

FUGRO NATIONAL, INC.

The ranges in Table 5.4-2 should encompass the costs which would be incurred by use of any of these procedures in a specific Verification program, regardless of physiographic province.

The recommendations contained in the following Tables (5.4-3, 5.4-4, 5.4-5) are primarily generic. Specific Verification programs will be tailored to the conditions existing in particular CSRs.

METHOD/QUANTITY	OBJECTIVE	EFFECTIVENESS	COMMENTS
Gravity	Basin shape; depth estimates to crystalline basement rock	Highly suited to alluvial filled or semi-closed basins having a significant, relatively abrupt density contrast with depth; accuracies commonly within 20%	Highly interpretive. Slow progress in in difficult terrain; useful for V&H modeling of basin shaft in "basin and range" type provinces. Should be "tuned" with other information such as seismic or borings. Recommend helicopter use to aid accessibility in rough terrain, although highly expensive.
Aeromagnetics	Locate possible shallow rock; estimate basin depth; approximate deep basin structure	Suited to areas with past igneous activity; including indications of volcanic flows; difficult to assess without specific post-interpretative drilling program	Rapid data acquisition followed by several weeks of interpretation, valuable in areas suspected of containing shallow igneous rocks, especially volcanic flows in basin fill. Recommend use very early in program to allow interpretive time and to design a verification program for detected anomalies.
Long Range "Deep" Seismic Refraction	Obtain gross deep layer velocity, structure and estimate basement depth	Good results where materials at depth propagate waves at higher velocity than overlying materials and where shallow materials are conducive to initial energy propagation; accuracies generally within 10%	Valuable for "tuning" gravity interpretations. Useful to V & H modeling of basin shape and seismic velocity profile and layer depths/thicknesses. May require large explosive charges and many shotholes. Recommend continued use in basin areas and use of multiple recording systems if many lines are done over short time interval.
Short Range "Shallow" Seismic Refraction	Determine compressional wave velocities of shallow deposits; determine depths to rock (material with velocity 7000'/sec.; 2134 m/sec) within construction zone	Suited to dry alluvium over rock; good results with accuracies generally within 10%	Very valuable; should be integretated with drilling and trenching program with information gathered concentrated in construction zone. In valley topography, valuable around perimeter for determining bedrock attitude. Access plays major role in productivity. Recommend continued use with "tapered" geophone interval for obtaining detailed shallow information. Use of component explosives allows crew increased mobility.
Downhole Seismic Velocity Measurements	Establish P&S wave velocities and determine dynamic elastic moduli of interrogated materials (to 500' deep)	Average velocities obtained if thin interbeds encountered; quality of results varied; consistently obtained poor record quality in ungrouted holes	Should be used in selected borings which have been prepared by casing and grouting. Provides economic way of obtaining P&S wave velocities in construction zone. Recommend continued use only in prepared borings, may be supplemented by other shear wave techniques such as refraction.
Downhole Geophysical Logging Techniques/ caliper, gamma-gamma, delta-gamma, neutron-gamma, neutron-epithermal-neutron, natural gamma	Establish feasibility for obtaining quantitative physical parameters of soils which otherwise are obtained by sampling and laboratory testing; analysis of stratigraphic continuity, determine depth to and thickness of ground-water zone	Little use for establishing stratigraphic continuity in alluvial deposits in widely separated borings; moderately effective for determining presence of ground-water; measured responses and resolution insufficient to provide reasonable quantitative measurements of engineering soils properties	May be useful when borings are closely spaced and when stratigraphy is suited to inter-boring correlation. In proper stratigraphic environment may provide inexpensive means of obtaining properties to depth. Recommend not continuing use unless subsurface conditions in specific area are conducive to providing good results. In general, more valuable information obtained from samples, especially for validation.
Electrical Resistivity	Obtain thicknesses of units of contrasting resistivity, average conductivity in construction zone. Locate highly resistive units in construction zone which may indicate excavation problems. Low resistivities may indicate presence of water.	Suited to soil covered areas which provide good electrode contact. Dry areas may require special electrode preparation. Rapid means of obtaining conductivities. Accuracies generally within 20%.	Interpretation well suited to computer providing rapid data turnaround. Should be done in conjunction with borings and seismic refraction. Provides valuable information on soil properties in construction zone. Field progress rapid. Limited to areas of low cultural noise (pipelines, transmission lines). Recommend continued use of shallow soundings as performed in characterization studies.

GEOPHYSICAL METHODOLOGY EVALUATION

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE
5.4-3

FUGRO NATIONAL, INC.

METHOD/QUANTITY	OBJECTIVE	EFFECTIVENESS	COMMENTS
Existing data gathering: local and regional publications, data, and sattelite immagery	Provide technical background and accurate planning base	Very effective for investigation planning base; most data good for rock descriptions and structure; little direct data on properties of Valley fill, ground water	Prevents duplication of effort; permits accurate planning. A more detailed search of site-specific literature and satellite imagery analysis should be accomplished for Validation.
Photogeology: entire Valley; 1:24,000 and 1:62,500 color stereo-pairs and photo indices	Delineate mappable units; define areas of potential hazard and difficult construction; identify terrain characteristics, and locate field data collection points	Extremely effective; color photos provide an excellent medium for delineating fan units at an ideal scale; IR did not generally add to the data base established from normal color in this Valley	Provides basis for accurate depiction of units, hazards & structure; good scale; IR could be tested again in a different physiographic setting if one is selected for Validation studies. Excellent for all Validation area; best method of evaluating large land areas
Field Reconnaissance / aerial and ground	Determine activity locations and access; define problem areas, familiarization with terrain and geotechnical conditions	Very effective; provided ground access is reasonable; aerial reconnaissance provided good overview for planning of mapping program	Air support required for rugged terrain, a necessary step in planning an effective field mapping program. Ground and aerial reconnaissance suggested for all areas with CSR well prior to planning a major field program
Field Mapping/ primarily in alluvial areas with classification of bedrock and investigation of *lineaments*	Verify and supplement the results of photogeology; determine final locations for field activities	Excellent results; very effective in documenting, modifying and validating interpretations made during photogeologic study	Provides excellent data base for Valley characterization; is needed to verify photogeology interpretations and to make detailed observations of actual field conditions and potential geologic hazards. Excellent and necessary for all Validation studies; the degree of mapping detail will vary with complexity of surficial geology, structure, and hard rock geology
Characterization of borings & trenches	Provide engineering geologic characterization of subsurface soils engineering data; define limits of geologic units	Good results; most effective with trenches, moderately effective with auger borings, limited effectiveness with wash borings	Is best performed by mapping team, trenches provide best exposures for comparison with surficial features Necessary to relate and extrapolate engineering properties to mappable geologic units; geologic mapping should precede where possible

ENGINEERING GEOLOGY
METHODOLOGY EVALUATION

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE
5.4-4

FUGRO NATIONAL, INC.

ACTIVITY	OBJECTIVE	EFFECTIVENESS	COMMENTS
Shallow Borings Hollow Stem Auger <100'/30m	Characterize and determine physical properties of geologic units and shallow subsurface soils units; determine depth to ground water, obtain undisturbed and bulk samples	Characterization not effective if geologic unit very thin or covers a large area with a variety of soil conditions; drilling method relatively fast and well suited to identifying subsurface units to 50' or 100'; generally not effective below 100' because of slow drilling rate	Equipment has good mobility in soft soil; drilling method is economical since no drilling fluids are required; good determination of moisture content and groundwater level. Should be continued for Validation program
Deep Borings Rotary Wash/air >100'/9m	Characterize and determine physical properties of geologic units and deep subsurface soils units; determine depth to ground water and depth to rock; obtain undisturbed samples	Poorly suited for geologic characterization; well suited for obtaining undisturbed samples and characterizing deep subsurface units	Need water truck for drilling; need temporary access roads to drilling site; more expensive than hollow stem auger drilling. Use compressed air when possible. Should be continued to Validation program.
Trenches	Characterize and determine physical properties of geologic units and shallow subsurface soils units; obtain bulk samples; evaluate cementation, excavatability and slope stability in the upper 10 to 20 feet	Very effective for characterization and identification of shallow units; can obtain good bulk samples of course material as compared to drilling; effective in evaluating cementation, excavatability, and slope stability	Expensive operation for depths 10' to 15'; slow operation if trench shored for detailed logging; track-mounted equipment needed where soft surface soils; extensive time needed to move between distant locations. Should be continued for Validation program; most trenches should be unshored.
Undisturbed Soil Sampling	Perform laboratory tests on samples to determine engineering properties	Pitcher samples best for unit weight, shear strength, and consolidation tests; not effective for moisture content because of drilling fluid infiltration; Fugro drive samples from hollow stem auger borings best for moisture determination, but samples disturbed during driving; split spoon samples obtained in clean sands or gravels when other sampling methods not effective	Can elminate moisture contamination of Pitcher samples by drilling with air; method limited to few soil types and is more expensive; cannot obtain Pitcher samples through hollow stem augers because inside diameter too small. Undisturbed samples essential for determining many soil properties
Bulk (disturbed) Sampling	For classification, determination of compaction, CBR characteristics, and suitability as an aggregate source	Best samples obtained from trenches; can obtain cuttings from hollow stem auger holes; cannot obtain sufficient amount of material in rotary wash borings	Large samples (50 lbs.) needed in coarse materials - trenching is best method; bulk samples only needed in upper 20 feet. Bulk samples needed for road design and suitability of materials for base course, concrete and backfill
Laboratory Testing	To determine engineering properties of subsurface units preliminarily to evaluate construction feasibility, provide data needed for V&H evaluations	Effectiveness depends on suitability of samples for measuring important parameters; limitations of sampling methods listed above; combination of sampling methods provides suitable results	Field laboratory near site area only effective if extensive study done in one area; well designed shipping boxes are essential to minimize sample disturbance during transport. Laboratory testing essential for determining soil properties, estimating construction costs, providing data for V&H evaluation

SOILS ENGINEERING
METHODOLOGY EVALUATION

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE
5.4-5

FUGRO NATIONAL, INC.

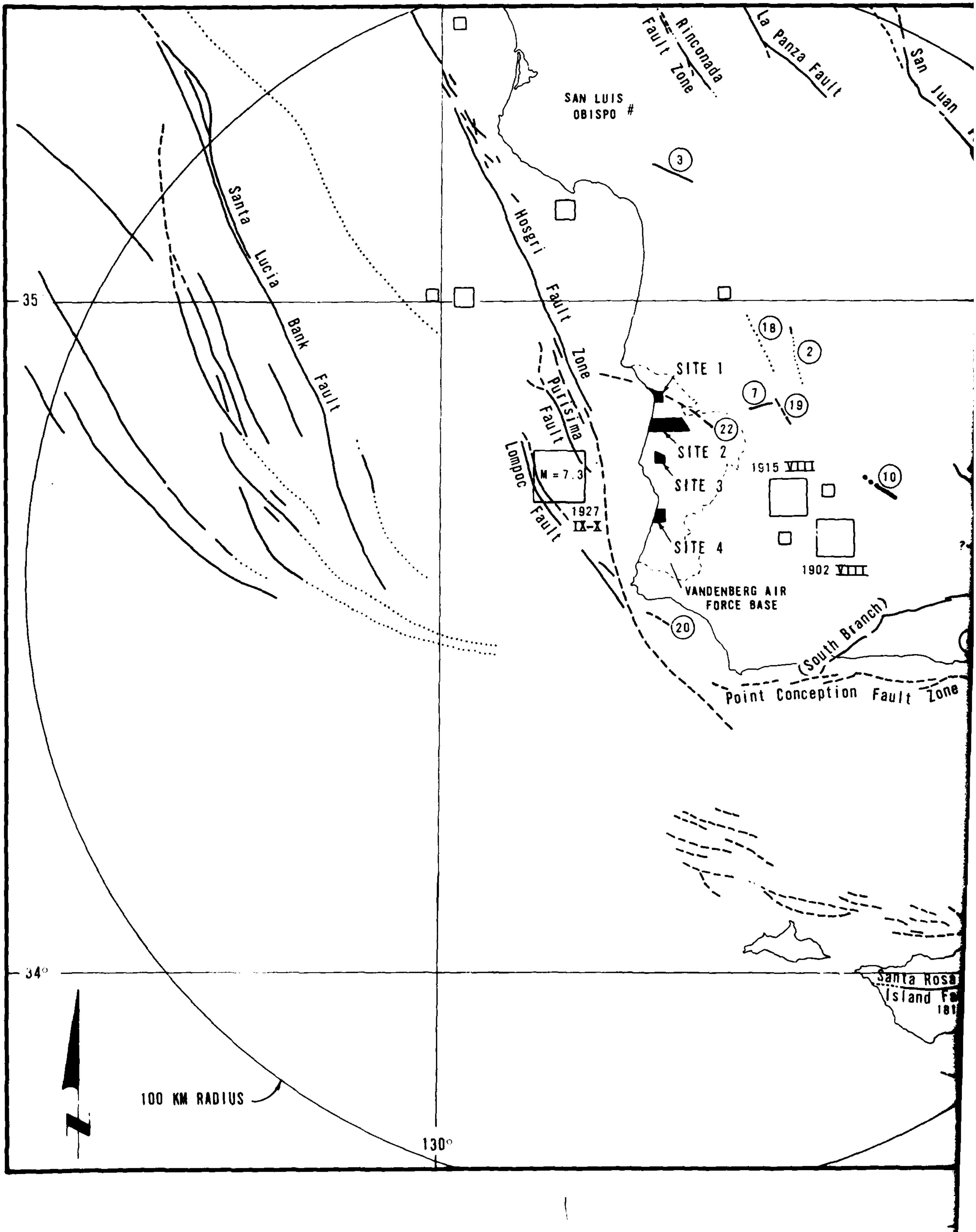
5.5 VANDENBERG GEOENVIRONMENTAL STUDY

This study was undertaken to support determination of environmental conditions at proposed MX test sites on Vandenberg Air Force Base, California. The key factors affecting site selection were:

1. Foundation conditions to depths affected by potential construction;
2. Geologic conditions such as landslides, mass wasting, excessive erosion, flooding, shallow ground water, and ground rupture (movement) along active faults which may prove hazardous to proposed facilities;
3. Seismicity of the local area which could affect design considerations and operational effectiveness;
4. Terrain and geomorphic features which may hamper facilities design or operation, or which may be sensitive and susceptible to irreparable environmental damage.

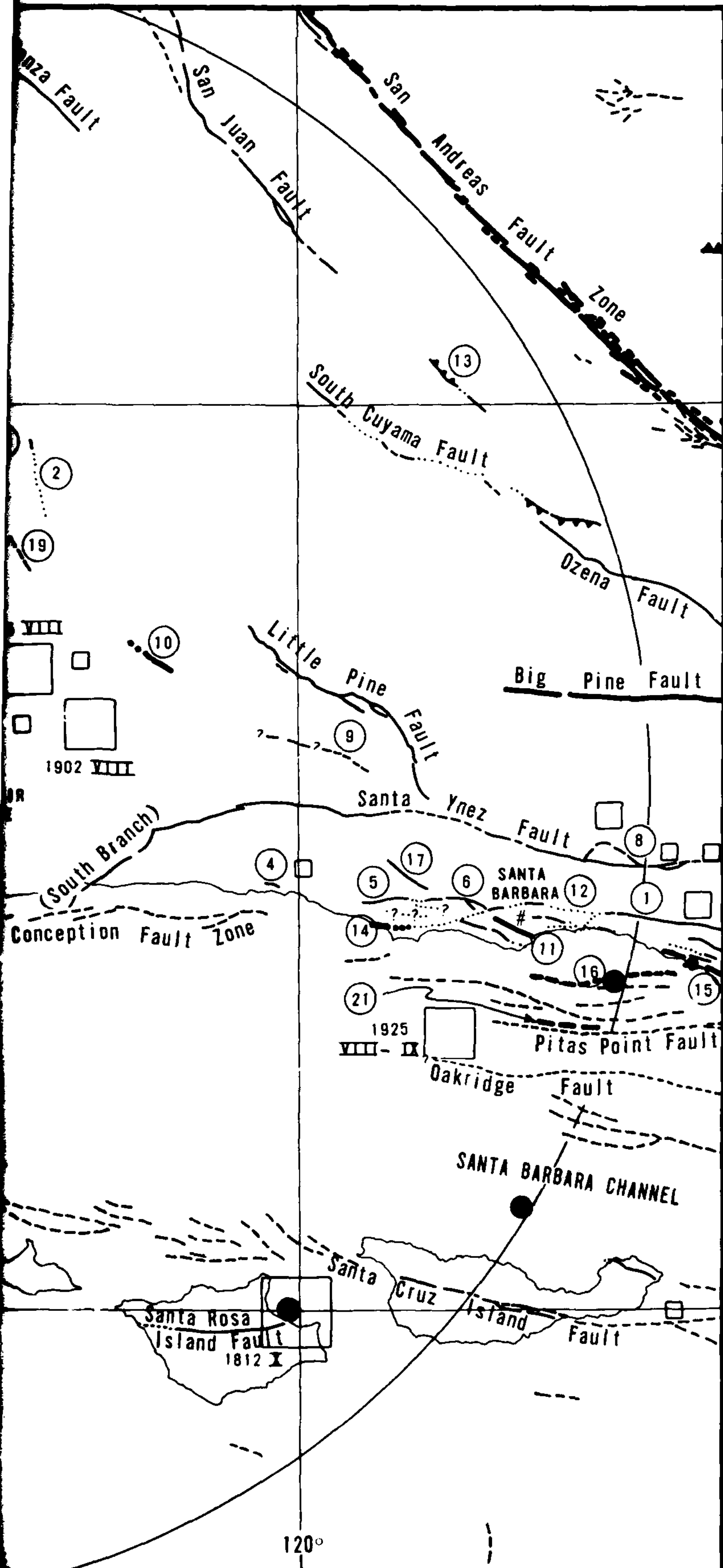
5.5.1 Scope of Investigation

Four potential site areas (Figure 5.5.1) were surveyed. They were studied by review of published and unpublished geologic, seismic and soils engineering reports, by analysis of aerial photographs, and by brief field investigations. Additional efforts were concentrated on Site 2 where one boring was drilled to assist in defining the general engineering properties of foundation materials. Also, a specific field investigation of the Lions Head fault, which crosses Site 1, was conducted to assess its earthquake and ground rupture potential. As part of this investigation, a short-duration microseismicity



Rinconada
Fault Zone
La Panza Fault
San Juan
SAN LUIS
OBISPO
Santa Lucia Bank Fault
Hosgri Fault Zone
35
SITE 1
SITE 2
SITE 3
SITE 4
Purisima Fault
Lompoc Fault
M = 7.3
1927
IX-X
1915 VIII
1902 VIII
VANDENBERG AIR
FORCE BASE
(South Branch)
Point Conception Fault Zone
34°
Santa Rosa
Island Fa
100 KM RADIUS
130°

1



EXPLANAT

ACTIVE FAULTS (1); DASHED WHERE A WHERE CONCEALED

POTENTIALLY ACTIVE FAULTS (1); DA DOTTED WHERE CONCE

EARTHQUAKE EPICENTERS (2); INSTRU THE TIME PERIOD 1932 T

VI-VII VII-VIII VIII-IX ≥ IX

ESTIMATED EPI MERCALLI) OF BETWEEN THE Y

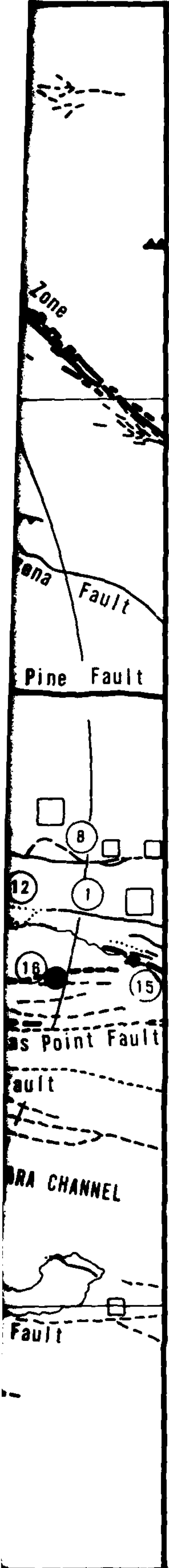
REFERENCES: (1) JENNINGS, 1975
ZIONY AND OTHERS, 19
PACIFIC GAS AND ELEC
H.C. WAGNER AND D.
MOORE AND TABER, 197
(2) *HILEMAN AND OTHERS,*
(3) COFFMAN AND VON HAKE

1	ARROYO PARIDA FAULT	8	JUNCAL CAMP
2	BRADLEY CANYON FAULT	9	LAKE CACHU
3	EDNA FAULT	10	LOS ALAMOS
4	ERBURU FAULT	11	MESA FAULT
5	GLEN ANNIE FAULT	12	MISSION RI
6	GOLETA FAULT	13	MORALES FA
7	GRACIOSA RIDGE FAULT	14	MORE RANCH

0 10 20 30 MILES

0 10 20 30 40 50 KILOMETERS

1:750,000



EXPLANATION

ACTIVE FAULTS[1]; DASHED WHERE APPROXIMATELY LOCATED, DOTTED WHERE CONCEALED OR INFERRED.

POTENTIALLY ACTIVE FAULTS[1]; DASHED WHERE APPROXIMATELY LOCATED, DOTTED WHERE CONCEALED OR INFERRED.

EARTHQUAKE EPICENTERS[2]; INSTRUMENTALLY RECORDED EVENTS DURING THE TIME PERIOD 1932 THROUGH 1975; $M \geq 5.0$

VI-VII VII-VIII VIII-IX ≥ IX

ESTIMATED EPICENTER AND INTENSITY (MAXIMUM MODIFIED MERCALLI) OF PRE-INSTRUMENTAL EARTHQUAKES OCCURRING BETWEEN THE YEARS 1769 THROUGH 1931

REFERENCES: (1) JENNINGS, 1975
ZIONY AND OTHERS, 1974
PACIFIC GAS AND ELECTRIC CO., DIABLO CANYON FSAR
H.C. WAGNER AND D. McCULLOCH, PERSONAL COMMUN., NOV. 1976
MOORE AND TABER, 1974

(2) HILEMAN AND OTHERS, 1973

(3) COFFMAN AND VON HAKE, 1973

1. ARROYO PARIDA FAULT
2. BRADLEY CANYON FAULT
3. EDNA FAULT
4. ERBURU FAULT
5. GLEN ANNIE FAULT
6. GOLETA FAULT
7. GRACIOSA RIDGE FAULT
8. JUNCAL CAMP FAULT
9. LAKE CACHUMA FAULT
10. LOS ALAMOS FAULT
11. MESA FAULT
12. MISSION RIDGE FAULT
13. MORALES FAULT
14. MORE RANCH FAULT
15. RED MOUNTAIN FAULT
16. RINCON POINT FAULT
17. SAN PEDRO FAULT
18. SANTA MARIA FAULT
19. SOLOMON CANYON FAULT
20. SUDDEN FLATS FAULT
21. UNNAMED
22. LIONS HEAD FAULT

0 10 20 30 MILES

0 10 20 30 40 50 KILOMETERS

1:750,000

QUATERNARY FAULTS AND SEISMICITY
VANDENBERG AIR FORCE BASE, CALIFORNIA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 5.5-1

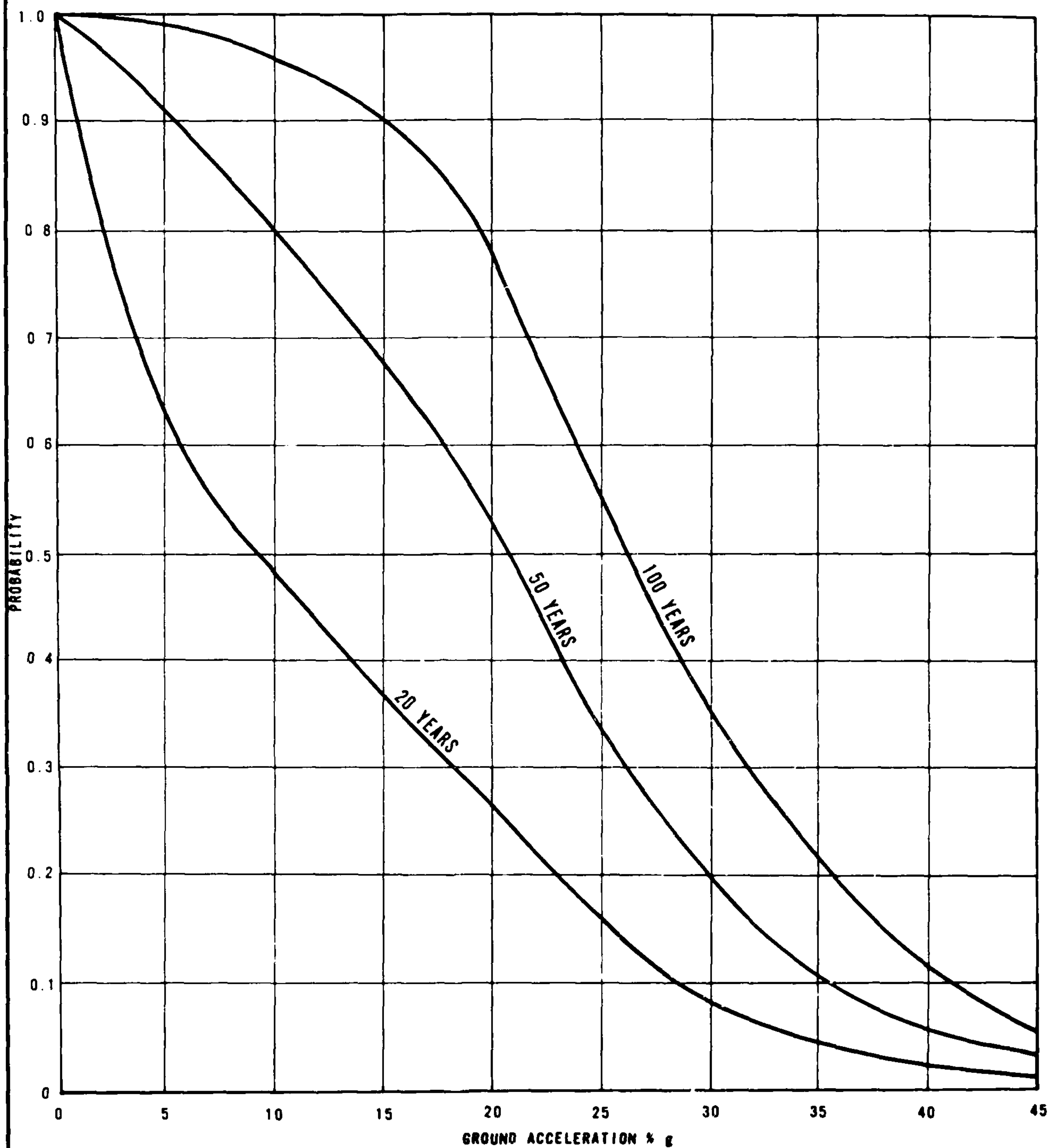
FUGRO NATIONAL, INC.

monitoring program was conducted in the northern Vandenberg Air Force Base area to help assess seismic potential in general and along the Lions Head fault in particular.

5.5.2 Summary of Results

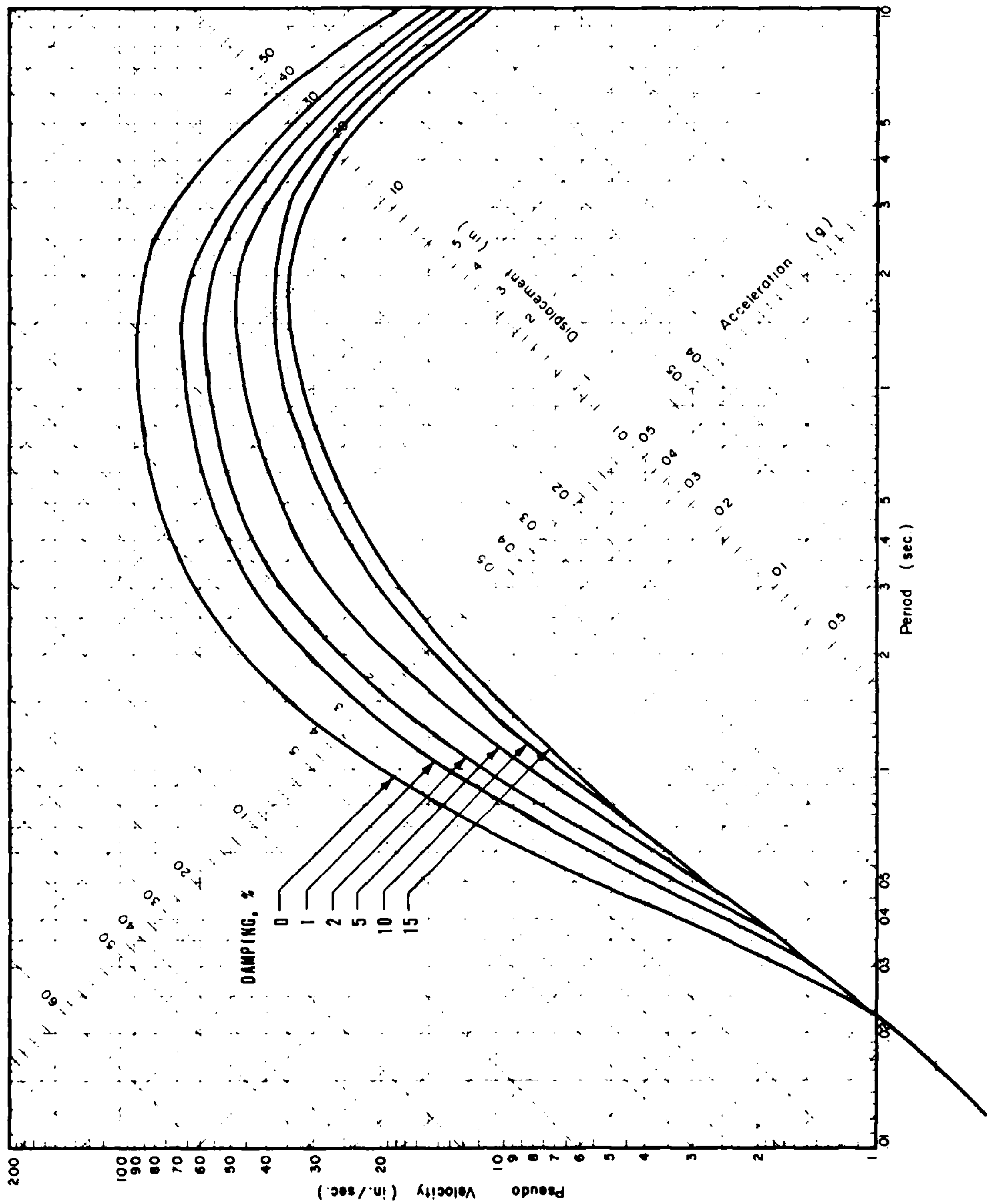
Ground-shaking due to activity of the offshore Hosgri fault could cause structural damage at all four sites. Sites 1 and 2 have the additional handicap of being close to the potentially active Lions Head fault. For the purpose of structural design, design spectra normalized to 0.70 g (Figure 5.5-2) should provide adequate protection against collapse of the structures due to earthquakes. All the sites have generally similar geologic and soil conditions and portions of each site are geotechnically suitable for the proposed test facility. Sites 3 and 4 appear the most favorable from a geotechnical standpoint.

The probability of exceeding a given acceleration level of vibratory ground motion for 20, 50, and 100 year periods is presented on Figure 5.5-3. The design acceleration for the maximum probable shaking is determined from the probability curve. Final selection of the probable design acceleration would be based upon the degree of risk considered acceptable.



PROBABILITY OF ACCELERATIONS GREATER THAN X %g AT A SITE IN THE SANTA BARBARA-VANDENBERG REGION.

PROBABILITY CURVES VANDENBERG AIR FORCE BASE, CALIFORNIA	
MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE - SAMSO	FIGURE 5.5-2
FUGRO NATIONAL, INC.	



NOTE: THESE SPECTRA ARE FOR HORIZONTAL RESPONSE: FOR VERTICAL RESPONSE MULTIPLY THE ACCELERATION ORDINATE BY 2/3

0.70g ELASTIC DESIGN SPECTRA FOR STRONGEST POTENTIAL VIBRATORY GROUND MOTION VANDENBERG AIR FORCE BASE, CALIFORNIA	
MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE - SAMSO	FIGURE 5.5-3

FUGRO NATIONAL, INC.

5.6 SOIL TEMPERATURE MONITORING

Soil temperature monitoring was initiated to obtain data concerning life support systems and provide information concerning thermal detectability. These concerns were based on deep well water temperatures at Luke where temperatures as high as 113°F (45°C) were measured.

5.6.1 Scope

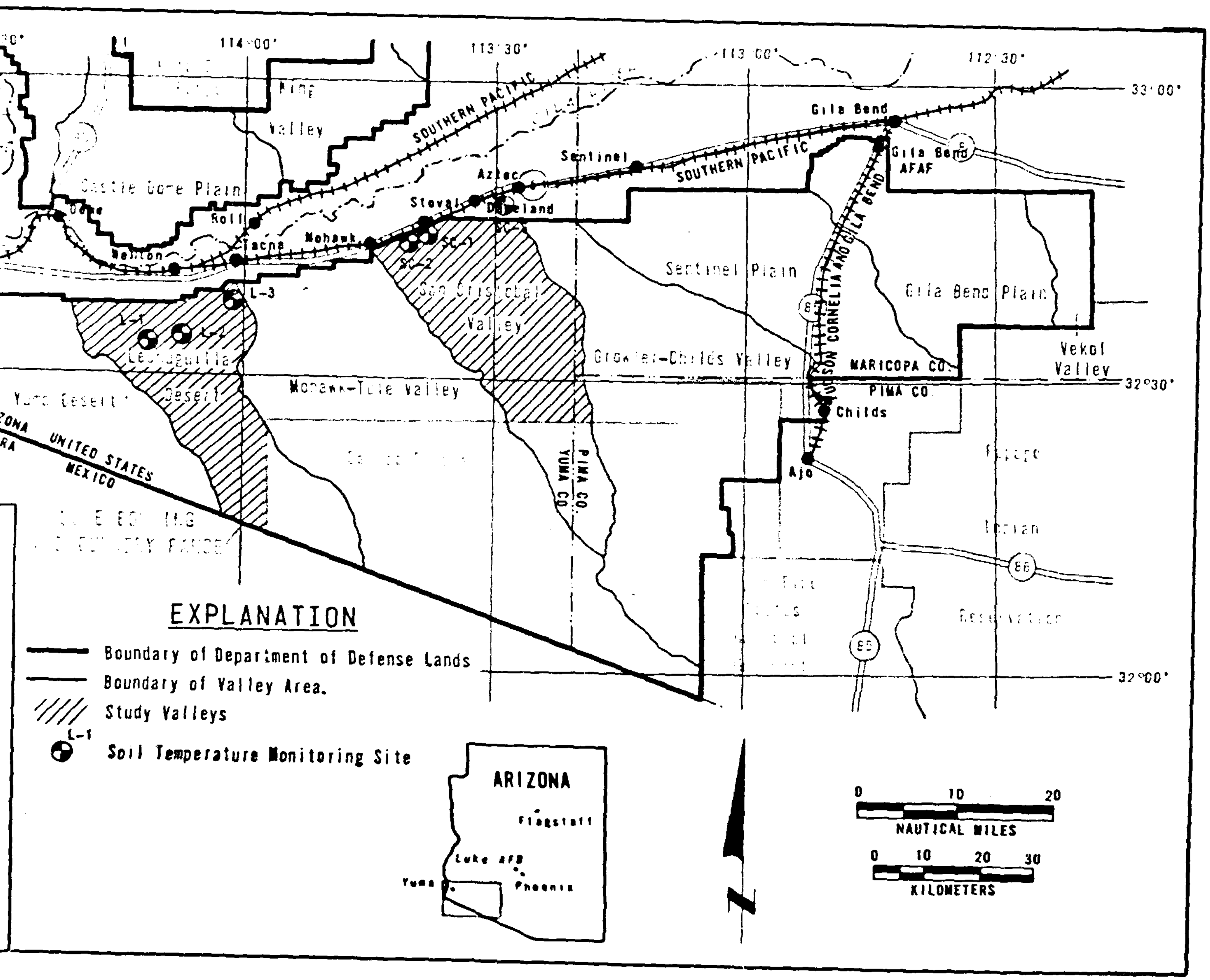
Three soil temperature monitoring sites were established in Lechuguilla Desert and three in San Cristobal Valley within LBGR (Figure 5.6-1). Two temperature sensors (redundant recording system) were installed at five-foot intervals to 30 feet (9 m) and monitored weekly from 7 January to 17 February 1977. Monthly monitoring was initiated 17 March 1977.

5.6.2 Results

Since implementation, soil temperatures in Lechuguilla Desert have generally decreased toward stabilization, deviating a total of nearly 8°F (5°C) from initial soil temperature readings, while those in San Cristobal Valley have generally increased as much as 5°F (3°C).

The following conclusions were made from this study:

1. Soil temperatures from approximately 65°F (18°C) to 85°F (29°C) may be expected in the subject valleys;



LOCATION MAP
SOIL TEMPERATURE MONITORING

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

5.6-1

NATIONAL

2. Variations in soil temperatures at each depth during the course of the monitoring program are the result of: (a) continuing thermocouple system stabilization, (b) fluctuations in air temperature for the five-foot depth, and (c) variations in soil moisture content at greater depths;

3. Soil temperatures do not appear abnormally high;

4. Spurious data points appear to have resulted from individual thermocouple malfunctions;

5. Statistical analysis of the soil temperature data indicates that the monitoring system employed has produced results that will allow representative soil temperatures to be determined.

AD-A114 214 FUGRO NATIONAL INC LONG BEACH CA F/G 8/6

MX SITING INVESTIGATION GEOTECHNICAL SITING STATUS REPORT. VOLU--ETC(U)

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5.7 BURIED TRENCH CONSTRUCTION TEST PROJECT

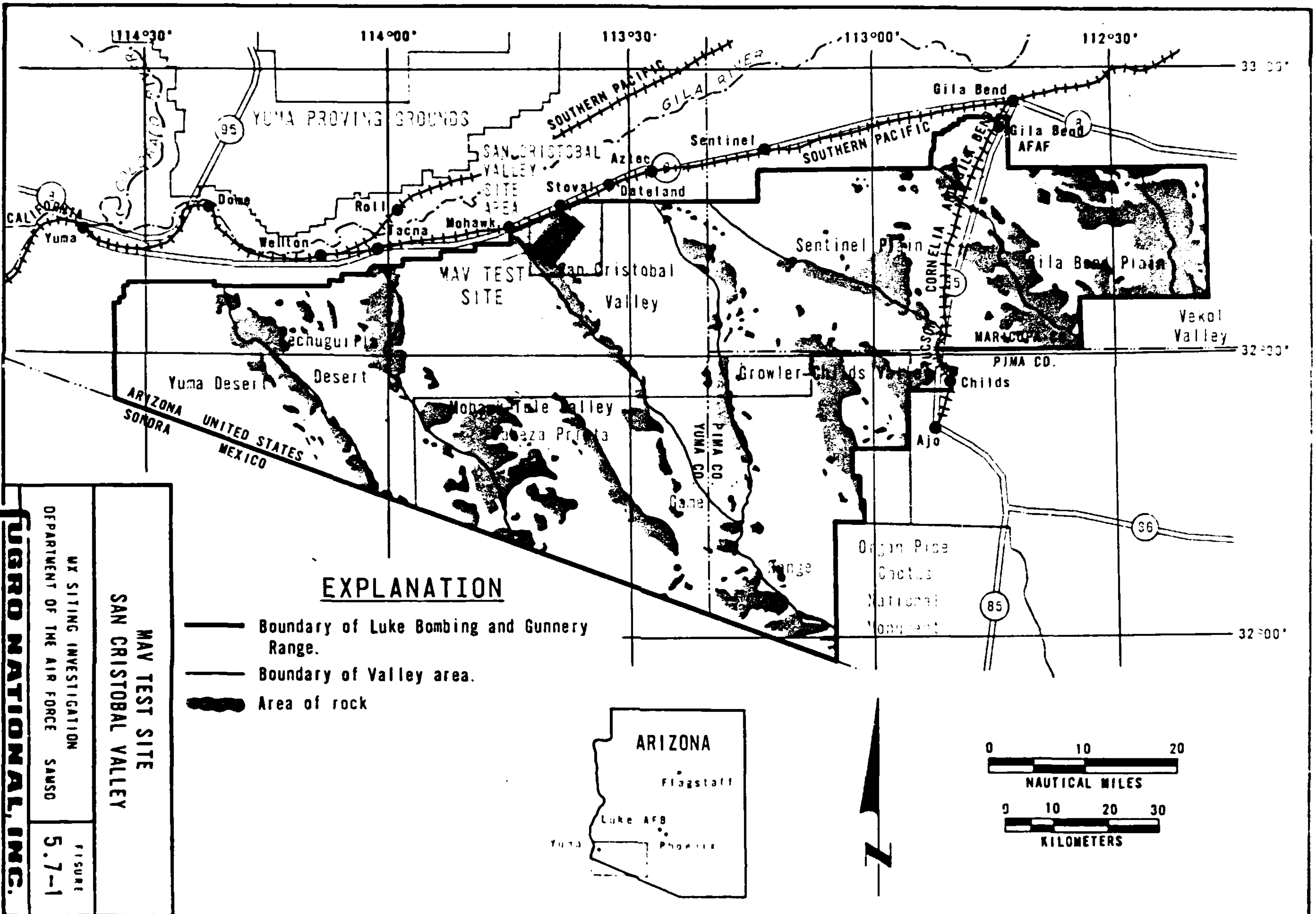
5.7.1 Background and Objectives

The primary purpose of the overall Multiple Aim Point Validation (MAV) program is to obtain cost and productivity rate information for construction of a prototype buried trench through geologic/soils conditions of the "typically variable" desert terrain within LBGR (Figure 5.7-1). Part 1 of the investigation was directed toward the selection of a primary MAV test site considering Childs Valley, Sentinel Plain, and San Cristobal Valley (Figure 5.7-1). Specific evaluation factors considered were; geology, soils, terrain, impact on LBGR activities, general environmental, logistics and physical access. Following selection of San Cristobal Valley as the MAV test site, a field investigation (Part 2) to confirm the valley conditions was implemented.

5.7.2 Scope of Investigation

The total scope of the investigation included:

- o Analysis of existing reports and data;
- o Field reconnaissance;
- o Interpretation of aerial photographs (scale 1:60,000);
- o Detailed geologic mapping in the test area;
- o Drilling 16 borings to a depth of 50 feet (15 m), and obtaining samples for laboratory testing;
- o Laboratory testing of soil samples;
- o Obtaining 39,340 feet (12,100 m) of seismic refraction profiles;
- o Analysis of all data and preparation of a report.



MAV TEST SITE
SAN CRISTOBAL VALLEY

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE 5.7-1

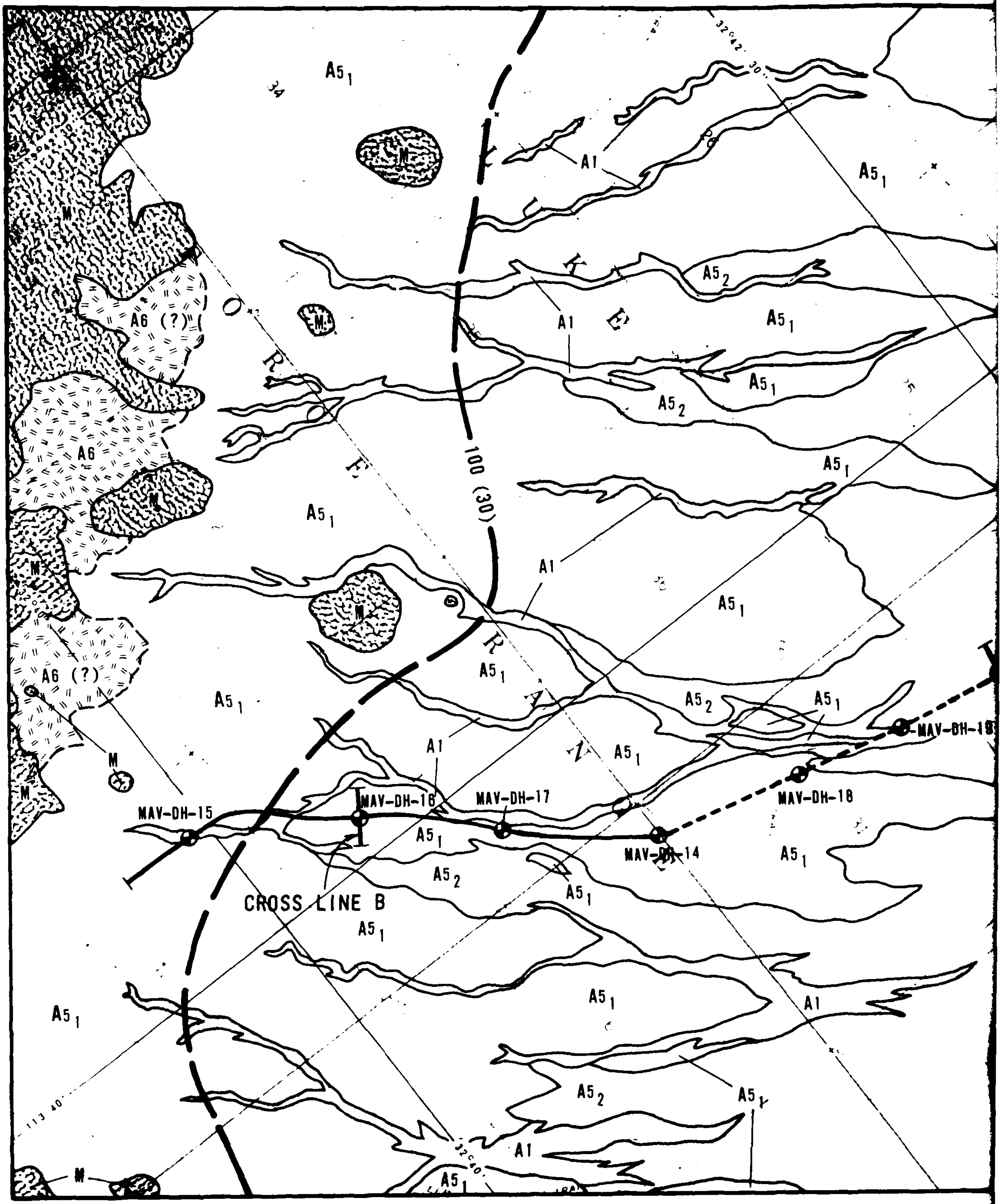
FUGRO NATIONAL, INC.

5.7.3 Results

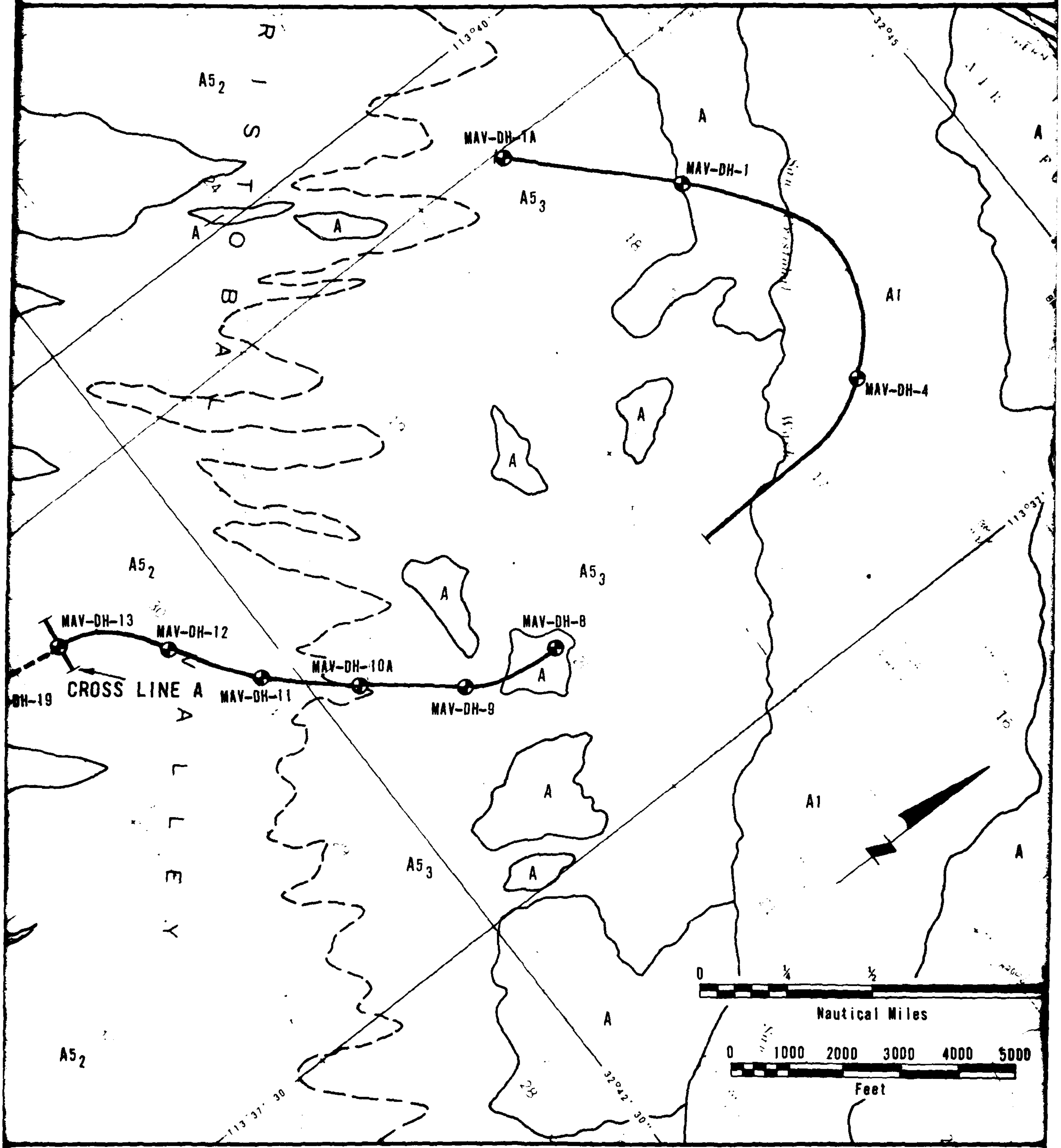
San Cristobal Valley was confirmed as a suitable MAV test site. Geologic conditions and the proposed MAV trench alignment are shown on Figure 5.7-2. Measured lithologic sections in the test area are shown on Figure 5.7-3.

Soils are extremely variable laterally and vertically along the alignment, consisting primarily of coarse gravel and sand near the Mohawk Mountains and fine sand, silt, and clay near the valley axis in San Cristobal Wash. Compressional seismic wave velocities range from 1100 to 4859 feet per second (340 to 1490 mps), and are greater than 5000 feet per second (1540 mps) where materials are saturated in areas of shallow ground water (50 feet; 15 m). Below one or two feet (0.5 m) of soft and loose material, the soils are dense to very dense. Most soils are slightly to moderately cemented.

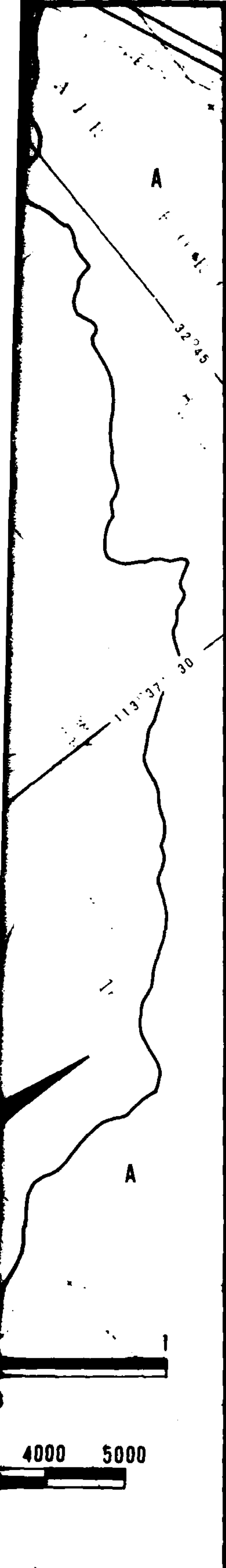
Based on the results of the investigation, it is concluded that most materials will be relatively easy to excavate with heavy duty excavation equipment. It is estimated that 90 to 95 percent of the trench can be excavated with vertical sides without support.



A5 1
A1
M
A6 (?)
A6
A5 2
100 (30)
MAV-DH-15
MAV-DH-16
MAV-DH-17
MAV-DH-14
MAV-DH-18
MAV-DH-19
CROSS LINE B



A5 2
A5 3
A
A1
MAV-DH-1A
MAV-DH-1
MAV-DH-4
MAV-DH-8
MAV-DH-9
MAV-DH-10A
MAV-DH-11
MAV-DH-12
MAV-DH-13
DH-19
CROSS LINE A
R I S T O B A
V A L L E Y
113°40'
32°45'
113°37'
113°37' 30
32°42' 30"
0 ¼ ½
Nautical Miles
0 1000 2000 3000 4000 5000
Feet



EXPLAN

BASIN FILL

Quaternary

Increasing Relative Age

A — UNDIFFERENTIATED SURFICIAL DEPOSITS - Predominantly loose silt and fine sand; poorl coarse sand and fine gravel on the surface. Deposited primarily by wind and wate on the basin floor.

A1 — STREAM CHANNEL AND FLOODPLAIN DEPOSITS - Loosely consolidated fine to coarse sand a axis. Grain size increases to fine gravel and cobbles in incised channels nearer deposition is along San Cristobal Wash and numerous tributary washes.

A5 — ALLUVIAL FAN DEPOSITS - $A5_3$ - Loosely consolidated admixtures of fine to coarse sa lag-gravel. This fan is an unvarnished, active surface of sediment transport gr stream channel and floodplain deposits.

$A5_2$ - Unconsolidated to poorly consolidated sand, silt, and sandy gravel, with va surface gravels forming isolated areas of desert pavement. This fan is in variou surface of sediment transport.

$A5_1$ - Well consolidated to moderately indurated admixtures of silt, sand, gravel varnished, well-paved surface, is an abandoned surface of sediment transport ele $A5_2$ and $A5_3$ alluvial fans. These fans form a near-continuous apron adjacent to

A6 — PEDIMENT DEPOSITS - Loosely consolidated gravel- to boulder-sized material derived phic rock complexes. Deposits are generally less than 10 feet thick and mantle mountain re-entrants.

Pre-Quaternary

ROCK

M — GRANITIC/METAMORPHIC ROCK ASSEMBLAGE - Complex rock assemblage composed predomina

SYMBOLS

GEOLOGIC CONTACT - Approximately located, dashed where indistinct o

100 (30) — 100-FOOT (30-METER) DEPTH TO ROCK CONTOUR - Approximately located.

MAV-DH-1 — LINE OF SEISMIC REFRACTION PROFILE - Dashed where approximately lo

MAV-DH-1 — MAV DRILL HOLE - Locations are approximate; MAV-DH-2, 3, 5, 6, 7 w

3

XPLANATION

sand; poorly graded with scattered residual
nd and water processes upon low gentle swales

arse sand and silt occurring near the valley
nels nearer the mountain front. Presently,

coarse sand and silt with scattered fine
ansport grading to the same base level as the

el, with variable amounts of unvarnished
s in various stages of abandonment as a

nd, gravel and cobbles. This fan, a deeply
nsport elevated three to five feet above the
djacent to the Mohawk Mountains.

ial derived from adjacent granitic and metamor-
and mantle planated rock shelves in shallow

predominantly of granite, gneiss and schist.

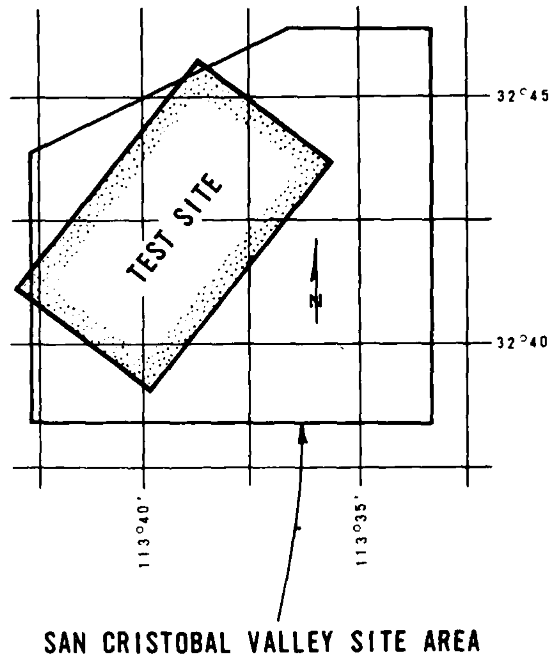
distinct or inferred.

located.

imately located.

5, 6, 7 were not drilled.

LOCATION MAP



ENGINEERING GEOLOGIC MAP
MAV TEST SITE

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 5.7-2

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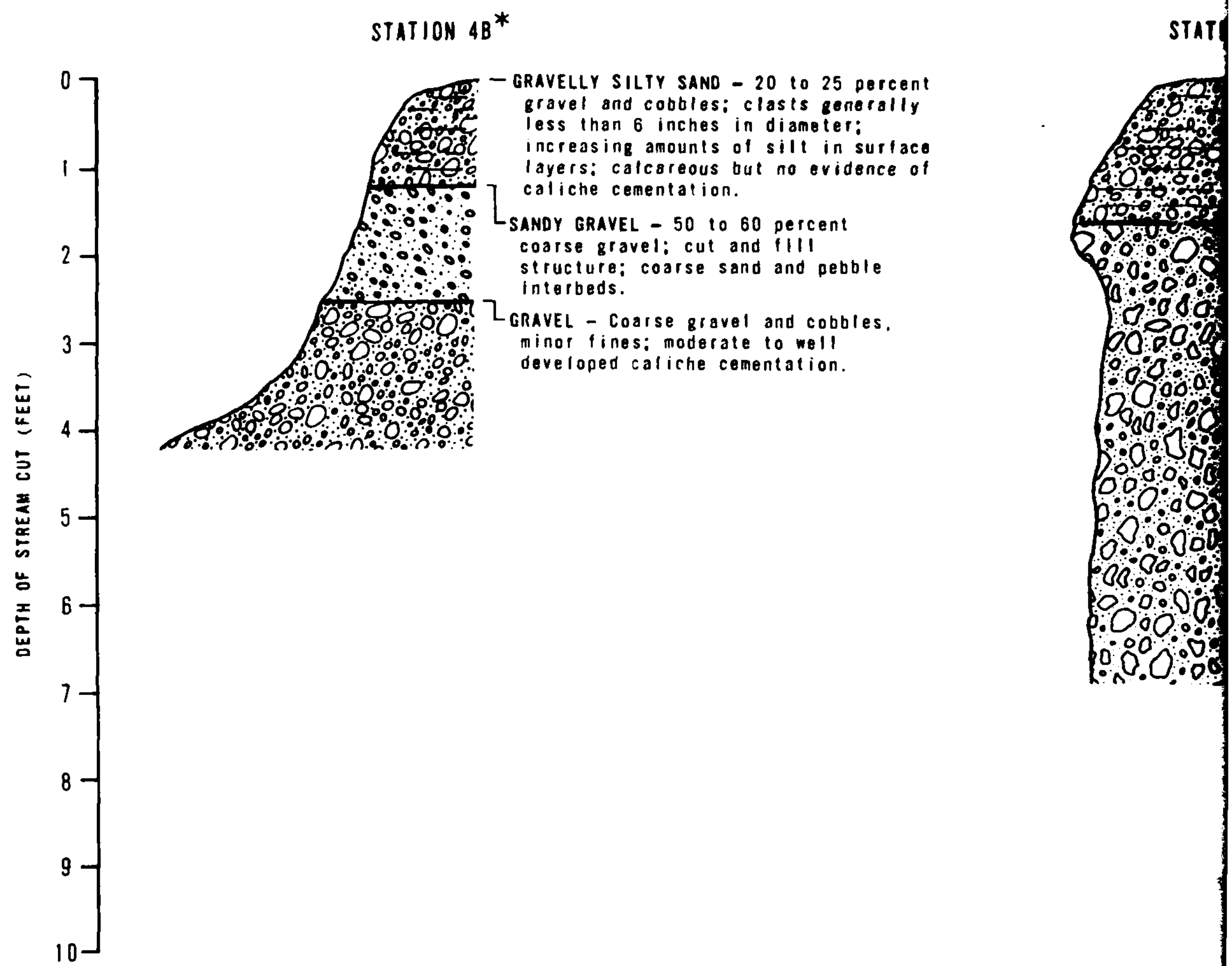
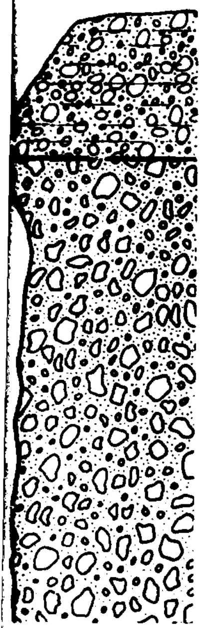


* LOCATIONS OF STATIONS SHOWN ON DRAWING 3

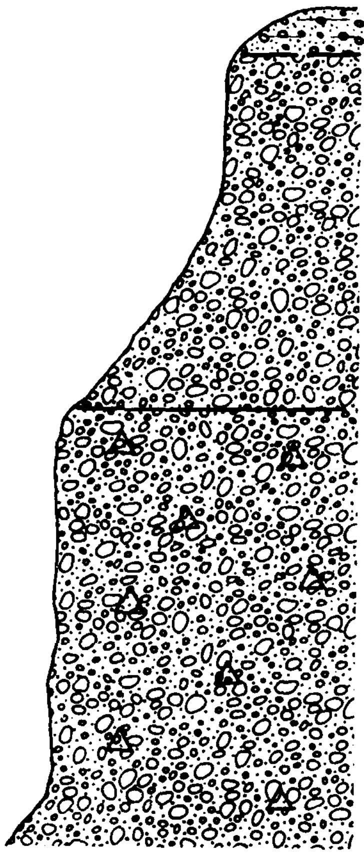
STATION 4C*



— GRAVELLY SILTY SAND - Locally 30 to 50 percent metamorphic gravel and cobbles, average diameter approximately 2 to 3 inches

— SANDY GRAVEL - 70 to 90 percent gravel to boulder-sized material; angular to subangular, metamorphic clasts to 1-foot in diameter. Moderate caliche cementation in matrix; caliche rinds on clasts are lacking; clasts break out of matrix with difficulty.

STATION 5*



— GRAVELLY SILTY SAND - Locally 30 to 50 percent coarse gravel.

SANDY GRAVEL - Light brown, well graded; clasts are predominantly subrounded gravel and cobbles, metamorphic in composition and ranging up to 8 inches in diameter averaging between 3 and 5 inches

— SANDY GRAVEL - Unit compositionally the same as above, but more highly calichified; the matrix is very dense to highly indurated on weathered surface exposures.

MEASURED LITHOLOGIC SECTIONS
SAN CRISTOBAL VALLEY SITE AREA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE SAMSO

FIGURE 5.7-3

FUGRO NATIONAL, INC.

6.0 FUTURE GEOTECHNICAL PROGRAM

6.1 GEOTECHNICAL VERIFICATION

One frequently learns about major projects in which actual costs are much higher than the original engineer's estimate and the bid price. A common reason is lack of adequate geotechnical data. Contractors have been quite successful in obtaining additional fees, either by change orders or by litigations.

Even though the three top ranked CSRs have a very similar ranking after completion of the preliminary geotechnical ranking (Section 4.0), construction costs could be significantly greater in one of the CSRs because of presently unknown geotechnical factors. A proper geotechnical Verification program will insure that site selection and design decisions are based on known rather than assumed conditions.

6.1.1 Objectives

It is necessary to geotechnically evaluate the three top ranking CSRs to (1) verify their overall suitability by confirming that conditions determined during characterization studies are sufficiently representative of the entire CSR area; (2) establish the prime CSR for Deployment Area Selection; (3) provide geotechnical data needed by agencies and sub-contractors in the fields of survivability/hardness and C^3; and (4) insure two viable alternatives to the prime CSR should it, for some non-geotechnical reason, be eliminated, or should a decision be made to split the MX force geographically.

6.1.1.1 Verify Characterization Results

Characterization studies have provided widely spaced field data on 5 to 20 percent of any given CSR. These data points generally lie on spacings of four to ten miles. Regardless of the relative homogeneity of the CSRs and the amount of existing data, this type of coverage will not suffice to define the nature of potential engineering and construction problems in a CSR. Depending upon variations required for each CSR, a similar data density (on the average) throughout a CSR would demonstrate the representative nature of characterization data and increase the confidence in conditions.

6.1.1.2 Prime CSR

The preliminary geotechnical ranking does not now appear to be highly definitive, i.e., the range of favorability is not high amongst the top three CSRs. However, subtle differences based on geotechnical characterization data could be extremely significant to final CSR selection when true ranges of sensitivities of the key variables are clearly known. Also, the possibility of geotechnical intervenors should be considered in light of the status MX will have in two years; the degree of defensibility the selection will have depends upon the use of the data base supporting the selection.

6.1.1.3 Viable Alternate CSRs

A program with the magnitude of MX must proceed to Deployment Area Selection with more than one Candidate Siting Region in order to retain flexibility should some impasse on the prime CSR be dictated by environmental, political, military or

strategic reasons. The ultimate degree of variation in favorability of the three selected CSRs will dictate the densities of data acquisition in each. Approaching Deployment Area Selection without some alternative for the possibility of a geographically split MX force could certainly cause schedule delays.

6.1.2 Field and Laboratory Studies

The available geologic, geophysical, soils, and terrain data from the characterization studies will provide a basis for defining the different levels of field study in each CSR. Detailed data will be obtained where expected conditions could have a significant impact on construction costs where little data are available for key geotechnical variables. In areas of relatively uniform soil conditions or where construction problems are expected to be minimal, only a reconnaissance level of study will be required. Other areas will require a moderate level of study.

The geotechnical techniques proposed are those which have proven to be most cost-effective during the methodology and characterization studies. The major emphasis on data collection will be on factors most likely to control construction and design (e.g., costs, schedules, techniques). The primary techniques to be used are as follows:

- Aerial photograph interpretation and field mapping
- Shallow seismic refraction and resistivity surveying
- Cone Penetrometer testing
- Borings, soil sampling, and laboratory testing

- o *Exploration trenching*
- o Aeromagnetic and ground gravity surveying

The photogrammetric base and engineering geologic mapping form the minimum basis for all other geotechnical studies. Engineering geologic interpretation of aerial photographs and field checking will be done for the entire area of each CSR. This study will be applied uniformly in each CSR, whereas the other techniques will vary in number and degree according to the level of study required. Soils engineering and geophysical techniques will be employed based on expected variations in subsurface conditions, systems requirements and available support.

The purpose of the engineering geologic studies will be to determine the specific characteristics of surficial geologic units, identify any geologic hazards and form a basis for interpretation and extrapolation of selected point-specific subsurface information. It will also allow an evaluation of surficial units as possible sources of coarse and fine aggregate for use in concrete, for shelter or trench construction materials, and as base course for road construction.

The soils engineering and geophysical investigations will be performed to determine the subsurface soil conditions, depth to water and rock, and basin shape as appropriate. The investigation will provide information primarily within the construction zone needed for design and cost estimating and for input into MX subsystems design and analysis. The major factors to

be determined are near-surface soil types and engineering properties required for road design, excavatability of the materials, and shear strength properties controlling stability of excavations. Field studies are proposed to determine quantities of potential aggregate sources and laboratory tests to evaluate suitability of aggregate sources and information about shallow ground-water conditions.

The levels of study recommended for the alternate CSRs will depend upon their ranking relative to the prime CSR. More initial Verification effort is justified on a higher ranked alternate CSR; if two approximately equal CSRs are available, the Verification investigations themselves would be relatively equal.

6.2 GEOTECHNICAL SUPPORT PROGRAMS

Geotechnical Verification studies will generate data for use by many in the MX program. The essential geotechnical support studies will be supported by field and laboratory Verification efforts, as well as discrete, site-specific field studies. The broad categories for supporting studies are:

- o Construction and Design
- o Environmental
- o Security; and Command, Control, Communication (C^3)
- o Survivability and Hardness

6.2.1 Construction and Design

While many support studies could be defined from within the MX program, the following are considered most important at present:

- o Road Design
- o Excavation and Construction Techniques
- o Aggregate Suitability
- o Water Resources
- o Earthquake Engineering
- o Backfill/Soil-Structure Interaction

6.2.1.1 Road Design

Extensive field and laboratory studies should be carried out for unsurfaced roads for the shelter concept. The loads of the missile TL are an order of magnitude greater than normal vehicle weights. Present road design concepts are based on extrapolations from available data; further research and testing are necessary. Considering the enormous impact on

total system costs of interconnecting roads for the shelter concept, additional road design studies are well justified.

6.2.1.2 Excavation and Construction Techniques

Prototype field studies of excavation and construction techniques are expected to continue in order to yield meaningful conclusions that should be supported by geotechnical information. By evaluating the geotechnical data as it relates to construction problems, it will be possible to predict with better accuracy the construction problems and costs for other siting areas where geotechnical data have been or will be obtained. Where unstable soil conditions are encountered, several different construction techniques should be evaluated. For the vertical shelter concept, the techniques might include guniting, installation of a steel liner, precast concrete segments, or slurry construction techniques. Where ground water is expected to be encountered, the construction options are dewatering or slurry construction methods.

6.2.1.3 Aggregate Suitability

Regardless of the basing mode selected, large quantities of concrete will be required. Since most siting areas are in remote regions where there is very limited aggregate production, aggregate studies will be required. Preliminary studies indicate that potential aggregate sources in many siting areas are available, but may not be suitable. Studies will be required to determine what sources are suitable for processing at the lowest possible cost.

6.2.1.4 Water Resources

Large quantities of water will be required for construction, processing materials, moisture conditioning of soils, dust control and personnel consumption during construction. In selected deployment areas, water resources studies will be required to determine the most economical method of producing the needed water. Such studies should include gathering the latest existing regional data on ground water conditions, drilling, determination of water quality, measurement of water depths and seasonal changes, and performing pump tests to determine transmissibility factors, and drawdown conditions. Preliminary water resources studies could be incorporated into the general Verification program.

6.2.1.5 Earthquake Engineering

For some basing mode concepts, portions of the MX system structures may not be designed to resist the high pressures due to nuclear blasts. However, all structures will probably be designed to resist some level of ground-shaking due to earthquakes. Design criteria will vary according to the seismicity of the siting area and the importance of the structure. Five of the seven CSRs are located within or adjacent to regions of relatively high seismicity; siting regions in Nevada are, in particular, in a highly seismic area. Studies will have to be performed to evaluate the earthquake response and aseismic design of facilities and structures which are not designed to resist high blast pressures.

6.2.1.6 Backfill/Soil-Structure Interaction

For several of the basing mode concepts, compacted backfill will be placed adjacent to and on top of the structure. The dynamic response of the backfill is a condition not well understood and the problem is compounded by a variety of soil types with a wide range in stiffness and strength properties. Studies need to be performed to obtain a better understanding of backfill/soil-structure interaction. From such studies, it should be possible to develop criteria for placement of backfill materials. The criteria used can have a significant effect on construction costs.

6.2.1.7 Energy

The review of existing literature during screening studies has provided an extensive data bank that includes locations of existing and potential energy sources. In addition to existing conventional power sources, known geothermal resource areas (KRGAs) could be developed to provide energy for the MX system.

Further studies pertaining to the prime and alternate CSRs would include compilation and presentation of all existing energy sources, transmission lines and transportation systems. Plans can then be made for primary and back-up energy systems. Selection from the available options would be based on an economic analysis of the relative costs and cost tradeoffs.

6.2.1.8 Raw Materials

Data pertaining to potential sources of construction materials

are also contained in the Fugro National data bank. This includes existing quarries, limestone deposits, petroleum resources and other natural resources. The final selection of raw material source areas will be initiated after selection of the prime and alternate CSRs.

6.2.2 Environmental

The types of geotechnical data to be collected and used for evaluation of key environmental variables impacting the MX basing mode and site selection evaluations, are those which are typically in an Environmental Impact Statement (EIS) or Final Environmental Statement (FES) (AFR 19-1 and 19-2). The nature of the geotechnical conditions can affect determinations of whether each environmental factor can be classed as exclusionary, mitigatable at some dollar cost (mitigated by relocation to another site or by preservation at the existing site), negligible, or enhanced when the construction and/or operation of MX is imposed into the environment. Examples of key environmental variables, associated with geotechnical conditions which may be expected to affect MX site evaluation, are fugitive dust potential, locations and production of raw materials, economic mineral resources, surface and ground water quality and quantity for construction and consumption along with the potential impacts of production and surface topography and character related to aesthetic values.

The prime geotechnical methods to be used in gathering geo-environmental data are photogeologic mapping of color stereo-

graphic pairs, field checking of photogeology, terrain analysis, bulk sampling of rock materials, shallow borings and trenches and laboratory testing. Water resources will be assessed by exploratory well drilling, development, ground water pump testing and quality analysis.

6.2.3 Command, Control, Communications and Security

Geophysical and engineering geology studies are needed to assure a survivable, flexible response capability and a secure nondetectable missile. Geophysical studies include earth conductivity, shallow ground temperatures, magnetic variations, ambient seismic and gravity. Photogeology and field checking coupled with digital terrain data will enable a full assessment of terrain and physiographic effects on C^3 and security. Trace rare earth element concentrations can be analyzed from undisturbed and bulk soil and rock samples collected during geologic mapping, drilling, and trenching. When systems criteria are synthesized, an investigation program to satisfy the C^3 and security Verification requirements should be prepared. The concept of broad area characterization with a representative number of specific Verification sites would be used.

6.2.4 Survivability and Hardness

Systems survivability estimates by various agencies and contractors have used calculations based on the geotechnical siting data. Currently, geotechnical S/H criteria have bounding values which are quite wide; the key variables are depth to rock and water (reflective/refractive interfaces), seismic velocities of

alluvial and rock materials, percent saturation, unit weight, shear strength, and various modulus values. Techniques to assess these criteria are similar to the general Verification work, however, the depth of investigation is significantly deeper. Gravity surveys, aeromagnetics, deep seismic profiling, deep resistivity soundings and minor deep drilling would be required, with the precise depth and numbers of data points depending upon the confidence limits and criteria boundaries established. An example of a study in which most of the required surveys were performed is the study conducted in Lechuguilla Desert, Arizona (Section 3.4).

An S/H characterization could be performed for the highest ranking CSRs, utilizing existing data and gathering new information through carefully selected additional surveys. This characterization would utilize the geologist/geophysicist team to bring a reasonable interpretation to the remotely sensed data.

6.3 PRECONSTRUCTION SURVEYS

6.3.1 Photogrammetric Data

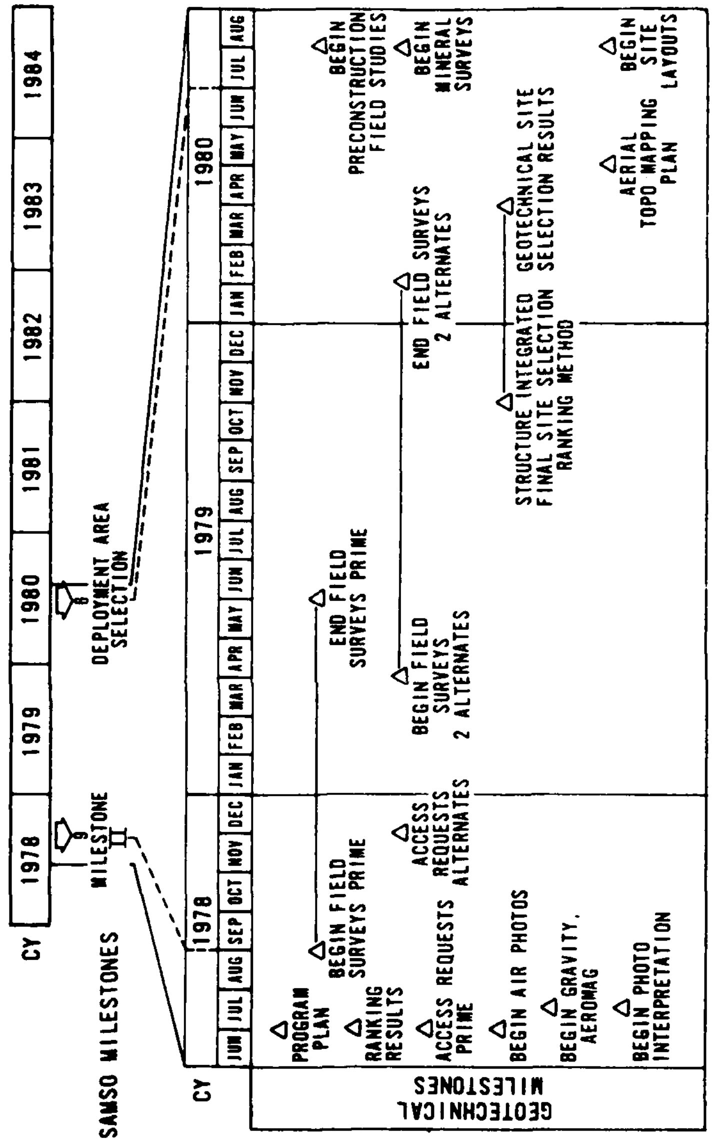
In most potential siting areas, existing topographic maps are not of sufficient detail. Therefore, once the deployment area has been selected, it will be necessary to obtain large-scale terrain information which can be used for planning and design. Aerial photographs at a scale of 1:4800 or larger will be required for the entire siting area to produce topographic maps with a contour interval of one foot. To accomplish this, field control points must be established and surveyed to determine coordinate locations. Analytical aerotriangulation is then performed to provide the necessary precision for production of maps and/or digital terrain data. The final format and scales of the terrain data will depend on system requirements.

6.3.2 Site Specific Geotechnical Studies

After completion of preliminary construction plans, a final geotechnical study will be required to provide specific foundation information for structures and facilities. The scope of the study will depend on the variability of the subsurface conditions in the siting area and the amount of geotechnical data available from the Verification program. The field investigation will primarily consist of drilling at structure locations. Limited geophysical and engineering geology studies will be required to provide data needed by construction, security personnel, C^3, or other subsystem groups.

6.4 SCHEDULE

Currently, Deployment Area(s) Selection, is scheduled for mid-CY 1980. Geotechnical results must be available to support this selection. The Screening, Characterization and support studies have provided data to allow ranking results for CSRs based on geotechnical-related parameters; these will be refined by July 1978. It is important that the geotechnical field studies begin in August with up-front access requests, aerial photography, aeromagnetic and gravity surveys. Specific "on-the-ground" surveys are planned to begin this fall. Verification efforts for the three selected CSRs (15,000 nm^2; 51,400 km^2) will require approximately 18 months. Proposed MX geotechnical activities are outlined on Table 6.1-1.



PROPOSED MX GEOTECHNICAL ACTIVITIES

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE 6.1-1

FUGRO NATIONAL, INC.

APPENDIX

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UNIFIED SOIL CLASSIFICATION SYSTEM (USCS)	A-17
EXPLANATION OF GEOLOGIC UNITS	A-18

FUGRO NATIONAL, INC. TECHNICAL REPORTS

FN-TR-1 Fugro National, Inc., 1975a, Siting evaluation report: Cons. report for SAMSO, v. I, 55 p., appendices.

TR-2 ___________, 1975b, Geotechnical report, White Sands Missile Range/Fort Bliss Military Reservation: Cons. report for SAMSO, v. IIA, 113 p., data summary sheets, appendices and graphics volume.

TR-3 ___________, 1975c, Geotechnical report, Yuma Proving Grounds/Luke-Williams Bombing and Gunnery Range: Cons. report for SAMSO, v. IIB, 122p., data summary sheets, appendices and graphics volume.

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GLOSSARY OF TERMS

ACTIVITY NUMBER - A designation composed of the valley abbreviation followed by the activity type and a unique number; may also be used to designate a particular location in a valley.

AEROMAGNETIC DATA - Magnetometer observations made from an airplane.

ALLUVIAL BASIN - A lowland area, generally between uplifted mountain blocks, filled with alluvial deposits.

ALLUVIAL FAN - A low, outspread, relatively flat to gently sloping mass of alluvium, shaped like an open fan or a segment of a cone, deposited by a stream (especially in a semiarid region) at the place where it issues from a narrow mountain valley upon a plain or broad valley. It is steepest near the mouth of the valley where its apex points upstream, and it slopes gently and convexly outward with gradually decreasing gradient.

ALLUVIAL FAN DEPOSITS - Alluvium deposited by a stream or other body of running water as a sorted or semisorted sediment in the form of a cone or fan at the base of a mountain slope.

ALLUVIAL PLAIN - A level or gently sloping tract or a slightly undulating land surface produced by extensive deposition of alluvium, usually adjacent to a river that periodically overflows its banks; it may be situated on a flood plain, a delta, or an alluvial fan.

ALLUVIUM - A general term for unconsolidated clay, silt, sand, gravel, and boulders deposited during relatively recent geologic time by a stream or other body of running water as a sorted or semisorted sediment in the bed of a stream or on its flood plain or delta, or as a cone or fan at the base of a mountain slope.

ANOMALY - 1) A deviation from uniformity in physical properties; especially a deviation from uniformity in physical properties of exploration interest. 2) A portion of a geophysical survey which is different in appearance from the survey in general.

AQUIFER - A permeable saturated zone below the earth's surface capable of conducting and yielding water as to a well.

GLOSSARY OF TERMS (Cont.)

ARKOSIC SANDSTONE - A sandstone with considerable feldspar, such as one containing minerals from coarse-grained quartzo-feldspathic rocks (granites, granodiorites, medium or high-grade schists) or from older, highly feldspathic sedimentary rocks; specifically a sandstone containing more than 25% feldspar and less than 20% matrix material of clay, sericite, and chlorite.

ARRIVAL - An event; the appearance of seismic energy on a seismic record; a line-up of coherent energy signifying the arrival of a new wave train.

ATTERBERG LIMITS - A general term applied to the various tests used to determine the various states of consistency of fine grained soils. The four states of consistency are solid, semisolid, plastic, and liquid.

Liquid limit (LL) - The water content corresponding to the arbitrary limit between the liquid and plastic states of consistency of a soil (ASTM D423-66).

Plastic limit (PL) - The water content corresponding to an arbitrary limit between the plastic and the semisolid states of consistency of a soil (ASTM D424-59).

Plasticity index (PI) - Numerical difference between the liquid limit and the plastic limit.

BASIN-FILL MATERIAL/BASIN-FILL DEPOSITS - Heterogenous detrital material deposited in a sedimentary basin.

BEDROCK - Rock with a seismic p-wave velocity of 7000 ft (2333 m) per second or more.

BOUGUER ANOMALY - The residual value obtained after latitude, elevation and terrain corrections have been applied to gravity data.

BOULDER FIELD - Five or more rocks, each with diameters of 6 ft or more occurring within an acre.

BULK SAMPLE - A disturbed soil sample (bag sample) obtained from cuttings brought to the ground surface by a drill rig auger or obtained from the walls of a trench excavation.

c - Cohesion (Shear strength of a soil not related to interparticle friction).

CALICHE - Gravel, sand or other material cemented principally by calcium carbonate.

GLOSSARY OF TERMS (Cont.)

CALIFORNIA BEARING RATIO (CBR) - A test performed on a specifically prepared soil sample which is useful in the design of road pavement to be supported by the soil tested (ASTM D1833-73). The load is applied on the penetration piston which is penetrated into the soil sample at a constant penetration rate. The bearing ratio reported for the soil is normally the one at 0.1 inches (2.5 mm) penetration.

CANDIDATE - One of some group of regions, areas or sites being considered for MX deployment. Removal of candidate from a specifically named region, area or site term indicates selection by SAMSO/MNND.

CANDIDATE DEPLOYMENT AREA (CDA) - An area encompassing between 500 and 1000 square nautical miles of potentially suitable land with either naturally or artificially defined boundaries designated for convenience of study, discussion and data depiction. The candidate deployment area could be composed of two to four parcels and should have a specific place name description.

CANDIDATE DEPLOYMENT PARCEL (CDP) - An area of 150 to 500 square nautical miles potentially suitable for MX siting which, when aggregated with others, forms a Candidate Deployment Area. Each parcel should have a specific geographic description. (In the Basin and Range Physiographic province a parcel may correspond to a geographic valley and in Texas to some agri-economic unit.)

CANDIDATE DEPLOYMENT SITE (CDS) - A non-specific (i.e. not finally approved) site proposed for some element of the MX system within a chosen deployment area (i.e. trench or shelter site).

CANDIDATE SITING PROVINCE (CSP) - An area potentially suitable for deployment of the MX system generally encompassing more than 6000 square nautical miles which, in a broad sense, is homogeneous with respect to most of the important characteristics governing siting of a total MX system.

CANDIDATE SITING REGION (CSR) - Potentially suitable area between 4000 and 6000 square nautical miles within one, or encompassing portions of more than one, candidate siting province which allows for full MX deployment.

GLOSSARY OF TERMS (Cont.)

CAPABLE (fault) - Movement at or near the surface at least once in the past 35,000 years, and/or more than once in the past 500,000 years, (Nuclear Regulatory Commission).

CAPROCK - A resistant, moderately to strongly cemented caliche layer forming a "cap" over less resistant layers.

CD TRIAXIAL SHEAR-A type of test to measure the shear strength of an undisturbed soil sample

CLOSED BASIN - A catchment area draining to some depression or lake within its area, from which water escapes only by evaporation.

COARSE-GRAINED - A term which applies to a soil of which more than one-half of the soil particles, by weight, are larger than 0.075 mm in diameter (passing the No. 200 U.S. size

COARSER-GRAINED - A term applied to alluvial fan deposits which are predominantly composed of material larger than 3 inches (76 mm) in diameter.

COLLUVIAL DEPOSITS - A general term applied to any loose, heterogenous, and incoherent mass of soil material or rock fragments deposited chiefly by dislodgement and downslope transport of the material under the direct application of gravitational body stresses. Material is usually found at the base of a steep slope or cliff.

COMPACTION TEST - A type of test to determine the relationship between the moisture content and density of a soil sample which is prepared in compacted layers at various water contents (ASTM D1557-70).

COMPRESSIBILITY-Property of a soil pertaining to its susceptibility to decrease in volume when subjected to load

COMPRESSIONAL WAVE -An elastic body wave in which particle motion is in the direction of propagation; the type of seismic wave assumed in conventional seismic exploration. Also called P-wave, dilatational wave, and longitudinal wave.

CONSOLIDATION TEST - A type of test to determine the compressibility of a soil sample. The sample is enclosed in the consolidometer which is then placed in the loading device. The load is applied in increments at certain time intervals and the change in thickness is recorded.

CONTERMINOUS UNITED STATES - The contiguous 48 states.

GLOSSARY OF TERMS (Cont.)

CORE SAMPLE - A cylindrical sample obtained with a rotating core barrel with a cutting bit at its lower end. Core samples are obtained from indurated deposits and in rock.

DEBRIS FLOW - A high-density flow of mud containing abundant coarse-grained materials (boulders, cobbles, gravel, sand) that frequently result from an unusually heavy rain.

DEGREE OF SATURATION - Ratio of volume of water in soil to total volume of voids.

DETECTOR - See GEOPHONE.

DIRECT SHEAR TEST - A type of test to measure the shear strength of a soil sample where the sample is forced to fail on a predetermined plane.

DISSECTION/DISSECTED (alluvial fans) - The cutting of stream channels into the surface of an alluvial fan by the movement (or flow) of water.

DISTAL - That portion of an alluvial deposit farthest from its point of origin.

DRY UNIT WEIGHT/DRY DENSITY - Weight per unit volume of the solid particles in a soil mass.

ELECTRICAL CONDUCTIVITY - Ability of a material to conduct electrical current

ELECTRICAL RESISTIVITY - Property of a material which resists flow of electrical current

ENTRENCH - The process whereby a stream erodes downward to form a trench.

EOLIAN - A term applied to materials which are deposited by wind.

EPHEMERAL(stream) - A stream in which water flow is discontinuous and of short duration.

EXTERNAL DRAINAGE - Stream drainage system whose downgradient flow is unrestricted by any topographic impediments.

EXTRUSIVE (rock) - Igneous rock that has been ejected onto the earth's surface (e.g., lava, basalt, rhyolite, andesite; detrital material, volcanic tuff, pumice).

FAULT - A plane or zone of rock fracture along which there has been displacement.

GLOSSARY OF TERMS (Cont.)

FAULT BLOCK MOUNTAINS - Mountains that are formed by normal faulting in which the surface crust is divided into structural, partially to entirely fault-bounded blocks of different elevations.

FINE-GRAINED - A term which applies to a soil of which more than one-half of the soil particles, by weight, are smaller than 0.075 mm in diameter (passing the No. 200 U.S. size sieve).

FINER-GRAINED - A term applied to alluvial fan deposits, which are composed predominantly of material less than 3 inches (76 mm)

FLOODING/LOW ENERGY FLOW - Flood waters flowing on a slope of low gradient.

FLUVIAL DEPOSITS - Material produced by river action; generally loose, moderately well-graded sands and gravel.

FORMATION - A mappable assemblage of rocks characterized by some degree of homogeneity or distinctiveness

FREE AIR ANOMALY - Gravity data which have been corrected for latitude and elevation (free air correction) but not for the density of rock between the datum and the plane of measurement (Bouguer correction).

FUGRO DRIVE SAMPLE - A 2.50 inch (6.4 cm) diameter soil sample obtained from a drill hole with a Fugro Drive Sampler. The Fugro drive sampler is a ring-lined barrel sampler containing 12 one-inch (2.54 cm) long brass sample rings. The sampler is advanced into the soil using a drop-hammer.

GAMMA - A unit of magnetic-field intensity. A gamma is 10^{-5} oersteds; sometimes expressed (incorrectly) as 10^{-5} gauss with which it is numerically equal.

GEOMORPHOLOGY - The study, classification, description, nature, origin, and development of present landforms and their relationships to underlying structures, and of the history of geologic changes as recorded by these surface features.

GEOPHONE - The instrument used to transform seismic energy into electrical voltage; a seismometer, jug, or pick-up.

GLOSSARY OF TERMS (Cont.)

GRAIN-SIZE ANALYSIS (GRADATION) - A type of test to determine the distribution of soil particle sizes in a given soil sample. The distribution of particle sizes larger than 0.075mm (retained on the No. 200 sieve) is determined by sieving, while the distribution of the particle sizes smaller than 0.075 mm is determined by a sedimentation process, using a hydrometer.

GRAVEL - Particles of rock that pass a 3-in. (76.2 mm) sieve and retained on a No. 4(4.75 mm0 sieve.

GRAVITY - The force of attraction between bodies because of their mass. Usually measured as the acceleration of gravity.

GRAVITY GRADIENT - The partial derivative of the acceleration of gravity with respect to distance in a particular direction, for which purpose the acceleration of gravity is considered as a scalar.

INTERIOR DRAINAGE - Stream drainage system that flows into a closed topographic low (basin).

INTRUSIVE (rock) - A rock formed by the process of emplacement of magma (liquid rock) in pre-existing rock. (e.g. granite, granodiorite, quartz monzonite).

LACUSTRINE DEPOSITS - Materials deposited in lake environment.

LINE - A linear array of observation points, such as a seismic line.

LIQUID LIMIT - See ATTERBERG LIMITS.

LOESS - A wind blown deposit predominantly silt or silty clay or clayey silt.

LOW ENERGY FLOW - See FLOODING.

MAGNETIC INTENSITY - A vector quantity measuring magnetic field strength. The unit of magnetic intensity commonly used in geophysical exploration is the gamma (see GAMMA).

MANTLED PLAYA - A playa surface or a portion of the surface that is covered with younger geologic material such as windblown sand, or alluvium.

MILLIGAL - A unit of acceleration used with gravity measurements; 1 milligal = 10^{-5} m/sec.^{2}. Abbreviated mgal.

MOISTURE CONTENT - The ratio, expressed as a percentage, of the weight of water contained in a soil sample to the oven-dry weight of the sample.

GLOSSARY OF TERMS (Cont.)

N VALUE - Penetration resistance, number of blows required to drive the standard split spoon sampler for the second and third six inches (0.15 m) with a 140 pound (63.5 kg) hammer falling 30 inches (0.76 m) (ASTM D1586-67).

OPTIMUM MOISTURE CONTENT - Moisture content at which a soil can be compacted to a maximum dry unit weight by a given compactive effort.

OVERBANK FLOODING - A large flow of water that overflows the sides of A stream channel.

ϕ - Angle of internal friction.

PATINA - A dark coating or thin outer layer produced on the surface of a rock or other material by weathering after long exposure (e.g., desert varnish).

PAVEMENT/DESERT PAVEMENT - When loose material containing pebble-sized or larger rocks is exposed to rainfall and wind action the finer dust and sand are blown or washed away and the pebbles gradually accumulate on the surface, forming a mosaic which protects the underlying finer material from wind attack. Pavement can also develop in finer-grained materials. In this case the armored surface is formed by dissolution and cementation of the grains involved.

PEGAMATITE DIKE - A coarse grained igneous rock of granitic composition that forms as a tabular intrusion that cuts across the planar structures of the surrounding rock.

P-WAVE - See COMPRESSIONAL WAVE.

PERIMETER SEISMIC REFRACTION SURVEY - Shallow seismic refraction measurements made around the perimeter of a valley.

PERMEABLE - The ability of liquid to pass through soil and/or rock material.

PICK-UP - See GEOPHONE.

GLOSSARY OF TERMS (Cont.)

PITCHER TUBE SAMPLE - An undisturbed, 2.87 inch (73 mm) diameter soil sample obtained from a drill hole with a Pitcher tube sampler. The primary components of this sampler are an outer rotating core barrel with a bit and an inner stationary, spring-loaded, thin-wall sampling tube which leads or trails the outer barrel drilling bit, depending upon the hardness of the material being penetrated.

PLASTIC LIMIT - See ATTERBERG LIMITS.

PLASTICITY INDEX - See ATTERBERG LIMITS.

PLAYA/PLAYA DEPOSITS - A term used in the southwest U.S. for a dried-up, flat-floored area composed of thin, evenly stratified sheets of fine clay, silt, or sand, and representing the lowest part of a shallow, completely closed or undrained, desert lake basin in which water accumulates and is quickly evaporated, usually leaving deposits of soluble salts.

PONDING (of water) - The accumulating of water in a topographic depression.

PRIME - Modifier used to indicate the highest ranking province, region, area, or site. If not an interdisciplinary ranking, then a qualifier should be used such as "prime" geotechnical candidate siting area".

PROXIMAL - That portion of an alluvial deposit nearest to its point of origin.

REGIONAL - The general attitude or configuration disregarding features smaller than a given size. The <u>regional gravity</u> is the gravity field produced by large-scale variations ignoring anomalies of smaller size. See residualize.

RELATIVE AGE - The relationship in age (oldest to youngest) between geologic units without specific regard to number of years.

RESIDUAL - What is left after a regional field has been removed, as in gravity or magnetic analysis. See RESIDUALIZE.

GLOSSARY OF TERMS (Cont.)

RESIDUALIZE - The process of separating a graphically depicted curve or a surface into its low-frequency parts (called the regional) and its high-frequency parts (called the residual). Residualizing is an attempt to sort out of the total field those anomalies which result from local structure; that is, to fine local anomalies by subtracting gross (regional) effects.

ROCK UNITS - Distinct rock masses with different characteristics (e.g., igneous, metamorphic, sedimentary).

S-WAVE - See SHEAR WAVE.

SAND - Soil passing through No. 4(4.75 mm) sieve and retained on No. 200 (0.075 mm) sieve.

SAND DUNE - A low ridge or hill consisting of loose sand deposited by the wind, found in various desert and coastal regions and generally where there is abundant surface sand.

SEISMIC - Having to do with elastic waves. Energy may be transmitted through the body of an elastic solid as P-waves (compressional waves) or S-waves(shear waves).

SEISMIC REFRACTION DATA: deep/shallow - Data derived from a type of seismic shooting based on the measurement of seismic energy as a function of time after the shot and of distance from the shot, by determining the arrival times of seismic waves which have travelled nearly parallel to the bedding in high-velocity layers, in order to map the depth to such layers.

SEISMOGRAM - A seismic record.

SEISMOMETER - See GEOPHONE.

SHEAR WAVE - A body wave in which the particle motion is perpendicular to the direction of propagation. Also called S-Wave or transverse wave.

SHEET FLOW - A process in which storm-borne water spreads as a thin, continuous veneer (sheet) over a large area.

SHEET SAND - A blanket deposit of sand which accumulates in shallow depressions or against rock outcrops, but does not have characteristic dune form.

SHOT - Any source of seismic energy; e.g., the detonation of an explosive.

SHOT POINT - The location of any source of seismic energy; e.g., the location where an explosive charge is detonated in one hole or in a pattern of holes to generate seismic energy. Abbreviated SP.

GLOSSARY OF TERMS (Cont.)

SILT AND CLAY - Fine-grained soil passing through No. 200 (0.075 mm) sieve.

SITE - Location of some specific activity or reference point. The term should always be modified to a precise meaning or be clearly understood from the context of the discussion.

SPECIFIC GRAVITY - The ratio of the weight in air of a given volume of soil solids at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature.

SPLIT SPOON SAMPLE - A disturbed sample obtained with a split spoon sampler with an outside diameter of 2.0 inches (5.1 cm). The sample consists of a split barrel which is driven into the soil using a drop-hammer.

SPREAD - The layout of geophone groups from which data from a single shot are recorded simultaneously. Spreads containing twenty-four geophones have been used in Fugro's seismic refraction surveys.

STREAM CHANNEL DEPOSITS - Materials (clay, silt, sand, gravel, cobbles, boulders) which have been deposited in a stream channel.

STREAM TERRACE DEPOSITS - Stream channel deposits no longer part of an active stream system, generally loose, moderately well graded sand and gravel.

SURFICIAL DEPOSIT - Unconsolidated residual and alluvial deposits occurring on or near the earth's surface.

TRANSITORY - A poorly defined, shallow ephemeral stream across an alluvial fan surface, the position of which is temporary and tends to shift frequently.

UNCONFINED COMPRESSION - A type of test to measure the compressive strength of an undisturbed soil sample.

UNIFIED SOIL CLASSIFICATION SYSTEM (USCS) - A system which determines soil classification on the basis of grain-size distribution and Atterberg Limits. (See page A-17).

GLOSSARY OF TERMS (Cont.)

VALLEY SEISMIC REFRACTION SURVEY - Deep seismic refraction measurements made near the middle of a valley to determine seismic wave propagation velocities and thickness of basin fill.

VELOCITY - Refers to the propagation rate of a seismic wave without implying any direction. Velocity is a property of the medium and not a vector quantity when used in this sense.

VELOCITY LAYER - A layer of rock or soil with a homogenous seismic velocity.

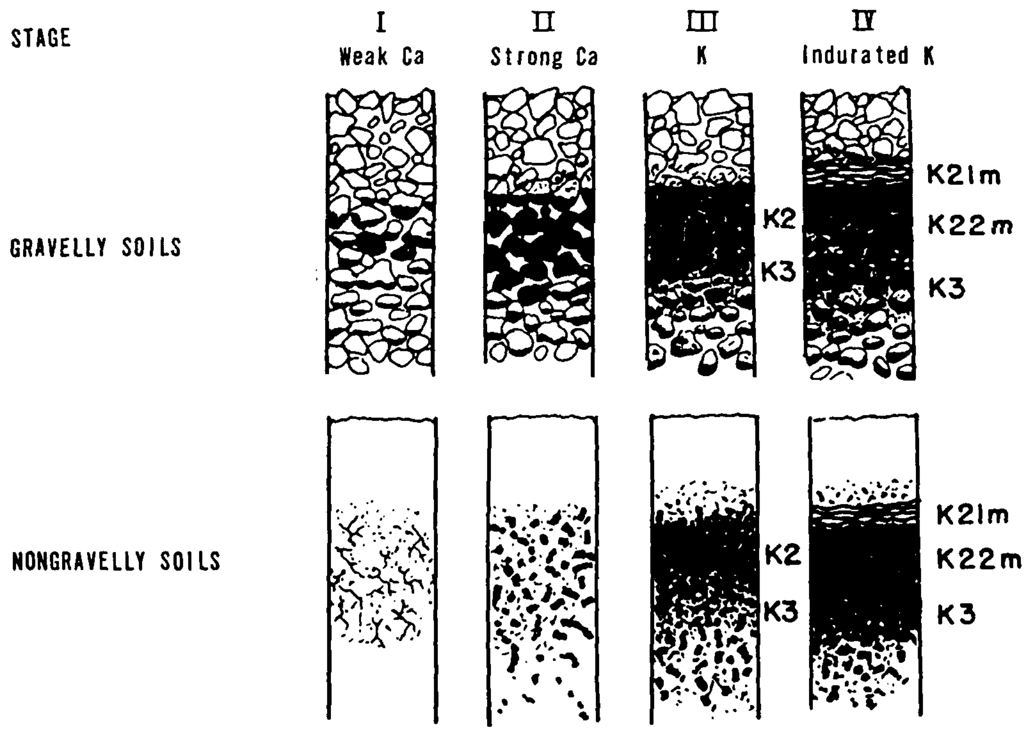
VELOCITY PROFILE - A cross-section showing the distribution of material seismic velocities as a function of depth and its configuration.

WASH SAMPLE - A sample obtained by screening the returned drilling fluid during rotary wash drilling to obtain lithologic information between samples.

Definitions were derived in part from Webster's New Collegiate Dictionary (1972 edition), Glossary of Geology (American Geological Institute, 1972), Encyclopedic Dictionary of Exploration Geophysics (Sheriff, 1973), and 1976 Annual Book Book of ASTM Standards.

DIAGNOSTIC CARBONATE MORPHOLOGY

STAGE	GRAVELLY SOILS	NONGRAVELLY SOILS
I	Thin, discontinuous pebble coatings	Few filaments or faint coatings
II	Continuous pebble coatings, some interpebble fillings	Few to abundant nodules, flakes, filaments
III	Many interpebble fillings	Many nodules and internodular fillings
IV	Laminar horizon overlying plugged horizon	Laminar horizon overlying plugged horizon



Stages of development of a caliche profile with time. Stage I represents incipient carbonate accumulation, followed by continuous build-up of carbonate until, in Stage IV, the soil is completely plugged.

Reference: Gile, L.H. Peterson, F.F., and Grossman, R.B., 1965, The K horizon: A master horizon of carbonate accumulation: Soil Science, v. 99, p. 74-82.

SUMMARY OF CALICHE DEVELOPMENT

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FUGRO NATIONAL, INC.

Major Divisions			Group Symbols	Typical Names	Field Identification Procedures (Excluding particles larger than 3 inches and basing fractions on estimated weights)			Information Required for Describing Soils
1	2		3	4	5			6
Coarse-grained Soils More than half of material is larger than No. 200 sieve size.	Gravels More than half of coarse fraction is larger than No. 4 sieve size. (For visual classification, the ¼-in. size may be used as equivalent to the No. 4 sieve size)	Clean Gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.			For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics.
			GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing			
		Gravels with Fines (Appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixtures.	Nonplastic fines or fines with low plasticity. (for identification procedures see ML below)			Give typical name; indicate approximate percentages of sand and gravel, max size, angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses
			GC	Clayey gravels, gravel-sand-clay mixtures.	Plastic fines (for identification procedures see CL below).			
	Sands More than half of coarse fraction is smaller than No. 4 sieve size.	Clean Sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.			
			SP	Poorly-graded sands, gravelly sands, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing			Example: Silty sand, gravelly; about 20% hard, angular gravel particles ½-in. maximum size; rounded and subangular sand grains coarse to fine, about 15% nonplastic fines with low dry strength; well compacted and moist in place; alluvial sand, (SM).
		Sands with Fines (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures.	Nonplastic fines or fines with low plasticity. (for identification procedures see ML below)			
			SC	Clayey sands, sand-clay mixtures.	Plastic fines (for identification procedures see CL below)			
Fine-grained Soils More than half of material is smaller than No. 200 sieve size. The No. 200 sieve size is about the smallest particle visible to the naked eye.					Identification Procedures on Fraction Smaller than No. 40 Sieve Size			
					Dry Strength (Crushing characteristics)	Dilatancy (Reaction to shaking)	Toughness (Consistency near PL)	
	Silts and Clays	Liquid limit less than 50	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	None to slight	Quick to slow	None	Give typical name, indicate degree and character of plasticity, amount and maximum size of coarse grains, color in wet condition, odor if any, local or geologic name, and other pertinent descriptive information; and symbol in parentheses.
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Medium to high	None to very slow	Medium	
			OL	Organic silts and organic silty clays of low plasticity.	Slight to medium	Slow	Slight	
	Silts and Clays	Liquid limit greater than 50	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Slight to medium	Slow to none	Slight to medium	For undisturbed soils and information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions.
			CH	Inorganic clays of high plasticity, fat clays.	High to very high	None	High	
			OH	Organic clays of medium to high plasticity, organic silts.	Medium to high	None to very slow	Slight to medium	Example: Clayey silt, brown, slightly plastic, small percentage of fine sand, numerous vertical root holes, firm and dry in place, loess, (ML).
Highly Organic Soils			Pt	Peat and other highly organic soils.	Readily identified by color, odor, spongy feel and frequently by fibrous texture			

UNIFIED SOIL CLASSIFICATION SYSTEM

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

A-17

FUGRO NATIONAL, INC.

NON-ROCK UNITS

(1) AREI SYMBOLS	MX (2) GEOLOGIC UNITS	
Au, Ast	Au	Non-rock Deposits (undifferentiated); fine- to coarse-grained materials deposited by alluvial, fluvial, eolian, lacustrine, gravity or glacial processes.
Aal	A1	Fluvial Deposits; predominantly composed of poorly- to well-graded sand and gravel with lesser amounts of silt- and boulder-sized material. The unit predominantly consists of recent water-laid deposits occupying present drainages and flood plains. - Older Fluvial Deposits (A1o) are generally thicker, more extensive units deposited in ancestral fluvial systems. - Alluvial Outwash Deposits (A1w) consist of mixed, geomorphically nondescript alluvial and fluvial deposits covering large, relatively flat, river and playa basins.
At	A2	Terrace Deposits; predominantly composed of moderately to well graded, clay- to gravel-sized material. Principally elevated terraces bordering modern streams (A2s) and lakes playas (A2l).
	A3	Eolian Deposits; predominantly composed of poorly graded sand-sized material deposited by wind action. Deposits may consist of mixed sand, silt, and clay (A3u), or be differentiated on the basis of predominant grain size and landform. A3s d - Predominantly fine sand-sized material deposited in sheets (A3s) or dunes (A3d). A3l - Loess composed predominantly of silt-sized material with lesser amounts of clay and fine sand. A3f - Predominantly clay-sized material with lesser amounts of silt and fine sand.
	A4	Lacustrine, Estuarine, and Playa Deposits; predominantly composed of poorly graded clay, silt, and fine sand deposited in bodies of standing water. Older lacustrine, estuarine, and playa deposits (A4o) are thicker, more extensive units occupying ancestral lake basins.
Aaf	A5	Alluvial Fan Deposits; predominantly composed of well graded sand and gravel with varying amounts of silt-, cobble-, and boulder-sized material. Deposited principally by distributary channels adjacent to mountain fronts. Relative ages are indicated by o - older, i - intermediate, or y - younger.
	A6	Pediment, Pediment Deposits, and Areas of Shallow Rock; planated bedrock shelf or near surface rock generally overlain by a thin mantle of sand- to boulder-sized residual or alluvial material.
	A7	Colluvial Deposits; predominantly composed of moderately- to well-graded sand and gravel with varying amounts of silt-, cobble-, and boulder-sized material. Deposited locally by gravity and water adjacent to steep gradients.

(1) AREI SYMBOLS	GE
gr	
Vu	
Vb	
Su	
Qtz	
Psa, Pm, Ph, Cau, Ls, Py, Par	
Qtz, gn	

NOTES: (1) AREI symbols were developed for use in the Aggregate Resources Evaluation Investigation (See Section 5.1 and Drawings 5.1A through 5.1C)

(2) MX Geologic units were used for Methodology, Screening, and Characterization studies.

ROCK UNITS

(1) AREI SYMBOLS	MX (2) GEOLOGIC UNITS		
			Shown in regions where rock is exposed; the areally predominant (greater than 70 percent) rock type is indicated. In those areas where two rock types occur the predominant rock type is shown followed by the subordinate rock type (e.g. S2MP/I4T).
	I		IGNEOUS (UNDIFFERENTIATED). Rocks formed by solidification of a molten or partially molten mass.
gr		I1	Intrusive - Typically crystalline, formed by the solidification of molten material below the surface (e.g., granite, syenite, diorite).
Vu		I2	Extrusive (undifferentiated). Formed by solidification of molten material at or near the surface.
Vb		I3	Extrusive (flows). Extrusive rocks formed by solidification of lava (e.g. basalt, dacite). I3b denotes young basaltic flows which may be interbedded with basin-fill materials.
		I4	Extrusive (volcaniclastic). Formed by accumulation, welding and or cementation of deposits of volcanic ejecta (e.g. tuff, agglomerate, lapilli).
Su	S		SEDIMENTARY (UNDIFFERENTIATED). Coarse- to fine-grained materials that exhibit some degree of cementation and were deposited by water, wind, gravity, or evaporation.
Qtz		S1	Sandstone. Composed predominantly of sand-sized particles.
Psa, Pm, Ph, Cau, Ls, Py, Par		S2	Limestone and Dolomite. Composed predominantly of carbonate material.
		S3	Shale. Composed predominantly of clay- and silt-sized particles (e.g. shale, siltstone, mudstone).
		S4	Evaporites. Sediments deposited from solution as a result of evaporation (e.g. gypsum, anhydrite, halite).
		S5	Clastics. Undifferentiated deposits composed of silt- to boulder-sized material. May be angular to rounded.
Qtz, gn	M		METAMORPHIC (UNDIFFERENTIATED). Rocks formed through alteration of igneous or sedimentary rock material by pressure, heat, or chemical changes below the weathered zone (e.g. gneiss, schist, slate, marble, quartzite).
	C		ROCK COMPLEXES. Indicated where no areally predominant (greater than 70 percent) rock type is present.

USEAGE

Modifying letter (r) indicates concentrations of resistant secondary carbonate (caliche), silicious, ferruginous and/or gypsiferous material, e.g. A5ir.

A3s/A5y - Mixed non-rock units; most areally extensive unit is listed first.

A5y(A5i) - Parenthetic unit underlies thin veneer of overlying mapped unit.

S5to - Established formations may have a supplemental letter added to distinguish formal designation (e.g. Tertiary Ogallala Fm.).

EXPLANATION OF GEOLOGIC UNITS

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

A-18

FUGRO NATIONAL, INC.

DAT

FILM